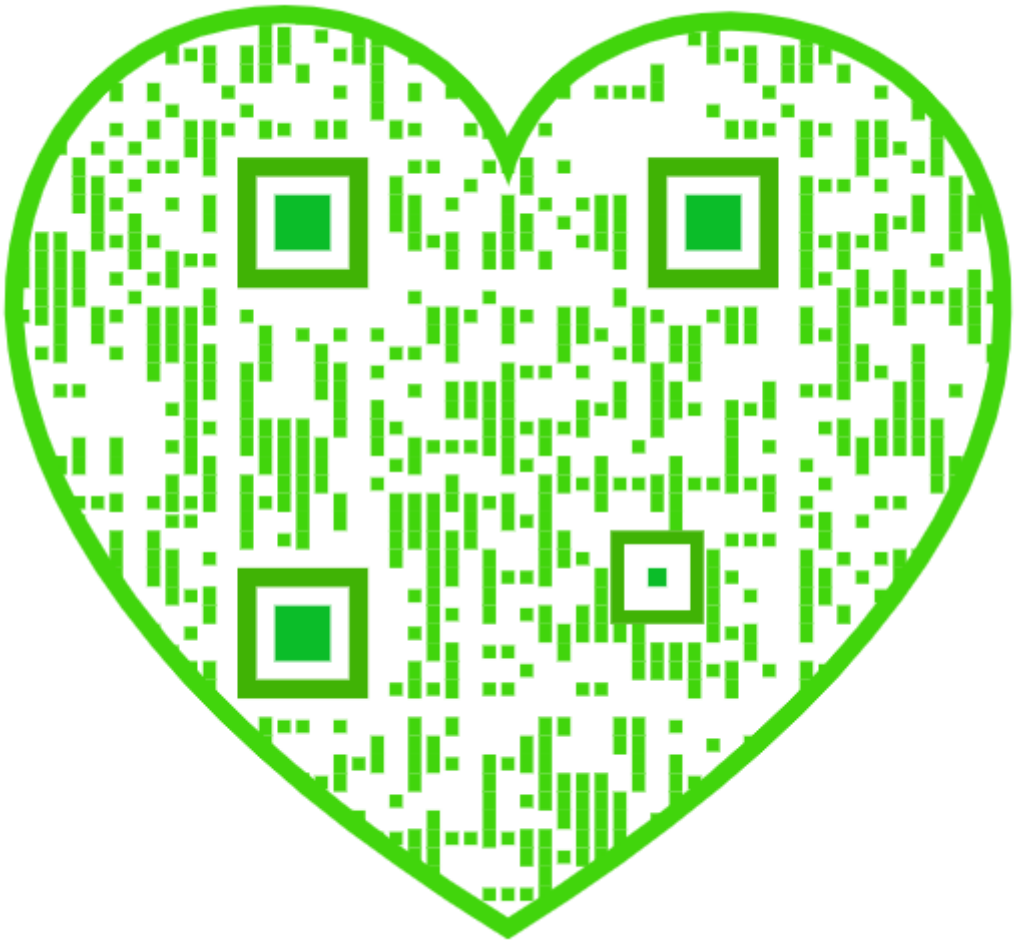


PRACTICAL AEROPLANE CONSTRUCTION

8161

PRACTICAL AEROPLANE CONSTRUCTION

A TREATISE ON MODERN WORKSHOP PRACTICE AS APPLIED TO THE BUILDING OF AIRCRAFT. A HANDBOOK FOR STUDENTS, APPRENTICES, AND DRAUGHTSMEN INTERESTED IN THE AERONAUTICAL INDUSTRY

BY

FREDERICK T. HILL

ASSOC. FELLOW R.A.SOC.; WHITWORTH EXHIBITIONER; LECTURER IN AIRCRAFT DESIGN AT THE IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, SOUTH KENSINGTON, AND THE POLYTECHNIC INSTITUTION, REGENT STREET

London

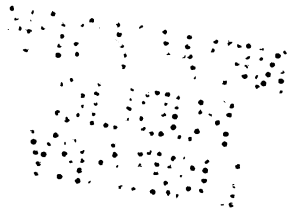
E. & F. N. SPON, LTD., 57 HAYMARKET, S.W. 1

New York

SPON & CHAMBERLAIN, 120 LIBERTY STREET

1920

THE NEW YORK
PUBLIC LIBRARY
ASTOR, LENOX AND
TILDEN FOUNDATIONS
R L



PREFACE

In adding this publication to what is already proving to be a somewhat extensive list of works on aeronautical matters, the author feels that some explanation is necessary. The notes upon which these chapters are based were originally made for the purpose of a series of lectures given to young apprentices in aircraft building, and it was realised at that time that there was a distinct gap between the published more or less theoretical works on design, and the actual practical work which an apprentice has to become familiar with in the shops. It is hoped that this book will at least help to bridge this gap, by offering to the apprentice who is not content to accept blindly the instructions given to him upon workshop processes by the various people with whom he works, an explanation of the general intentions underlying those procedures which he meets with.

The book is also recommended to the junior draughtsman who is engaged upon aircraft design, to whom a comprehensive knowledge of the possible ways of manufacturing the article which he is designing is an exceedingly important part of his stock in trade.

1 9 1921

Every endeavour has been made to keep the language of the text as non-technical as possible, and a feature has been made of the illustrations used to supplement the explanations of the different processes. It is felt that the book will consequently appeal to many members of the general public who may be interested in a science which must eventually play a very important part in the world's future history.

In conclusion, the author would like to extend his thanks to his many friends in the aircraft industry for the assistance willingly given in the collection of this information, and particularly to Mr H. Reynolds for the preparation of the set of illustrations.

F. T. HILL.

CONTENTS

CHAP.		PAGE
1.	STEEL CONSTRUCTION AS APPLIED TO AIRCRAFT	1
2.	PRESS TOOLS: THEIR SELECTION AND APPLICATION TO AIRCRAFT PARTS	27
3.	CONSTRUCTION OF TANKS	55
4.	GENERAL SAWMILL WORK	83
5	BUILDING OF SMALL DETAILS IN TIMBER	104
6	WOODWORK ASSEMBLING-SHOP WORK	130
7.	BUILDING OF AIRSCREWS	150
8.	COVERING, DOPING, AND VARNISHING OF THE COMPONENTS OF AEROPLANES	171
9.	INSPECTION OF AIRCRAFT PARTS	188
10.	ERECTING AND RIGGING AN AEROPLANE	213
	INDEX	234

PRACTICAL AEROPLANE CONSTRUCTION

CHAPTER I

STEEL CONSTRUCTION AS APPLIED TO AIRCRAFT

THE utilisation of steel in the construction of aircraft is attended by certain limitations imposed by the need for the greatest possible efficacy in terms of the load per unit of power available. Lengthy discussions and a large amount of research have, however, led designers to the conclusion that steel in one or another form is practically a necessity in the construction of the following parts and components :—

(1) The fuselage or body, almost entirely steel tube.

(2) The engine platform supports, steel tube and plate.

(3) The trailing edges of planes and ailerons, etc.

It is further tolerably certain that "all-metal" aeroplanes will be the standard machines of the future, several firms of repute having already designed and built them with a great measure of

success. Fire prevention, a greater degree of uniformity in strength of the materials being used, certainty of supply of material, and greater weather-proofness of the parts, are all factors in favour of metal construction wherever possible.

It is seldom that one finds anything but steel plate and tube as the material of which wiring plates, sockets, wires, bolts, and nuts are made. Steel plate is obtainable in a number of qualities, the most common being known as "mild steel." This is iron freed from such impurities as sulphur, phosphorus, silicon, etc., and given a small amount of carbon. It can be welded, soldered, brazed, and forged, but cannot be hardened. This grade of steel cannot be used for highly stressed parts, in which case higher qualities such as nickel chrome and chrome vanadium are largely used.

In order to amplify the foregoing, take, in detail, the materials used in a typical steel body.

Steel tube is usually the basis of this form of construction. This material has been developed to an extraordinary degree since being used for aircraft, and can be obtained in practically any size and length within reason. Being of the weldless, *i.e.* jointless and solid-drawn, type, it has not only great strength combined with lightness, but it is easily manipulated to any shape that may be required.

Consider what is commonly known as the top longeron; this is a combination of three steel tubes,

the bent nose portion and two straight pieces each jointed with a sleeve. The first operation in the construction of this member is the laying out of the curve of the nose portion on a suitable board, transferring the lines and dimensions set out on the design in a similar manner to ordinary drawing. The tube is then placed in a set of bending rollers (see fig. 1) and bent to the required shape. Great care is necessary in this operation, as it is comparatively easy to kink or otherwise damage the metal. The actual practice adopted in many shops varies, some considering that it is necessary to fill the tube with sand and bend after heating to a cherry-red colour, whereas others bend cold. The adoption of either method depends on the gauge or thickness of the tube, the radii of the bend, and the amount of the strain that the member is required to take up.

It is, however, certain that, in the future, the bending of tubes cold will become more popular, by reason of the special appliances available and the attention given to the question of production when designing curved members of a steel frame. It will therefore be safe to omit any mention of the actual operations entailed when bending steel tubes hot, and concentrate attention on the appliances and methods used in cold bending.

The arrangement of rollers shown in fig. 1 is an extremely simple one for the cold bending of tubes. First screw the adjustable roller (*a*) on to the

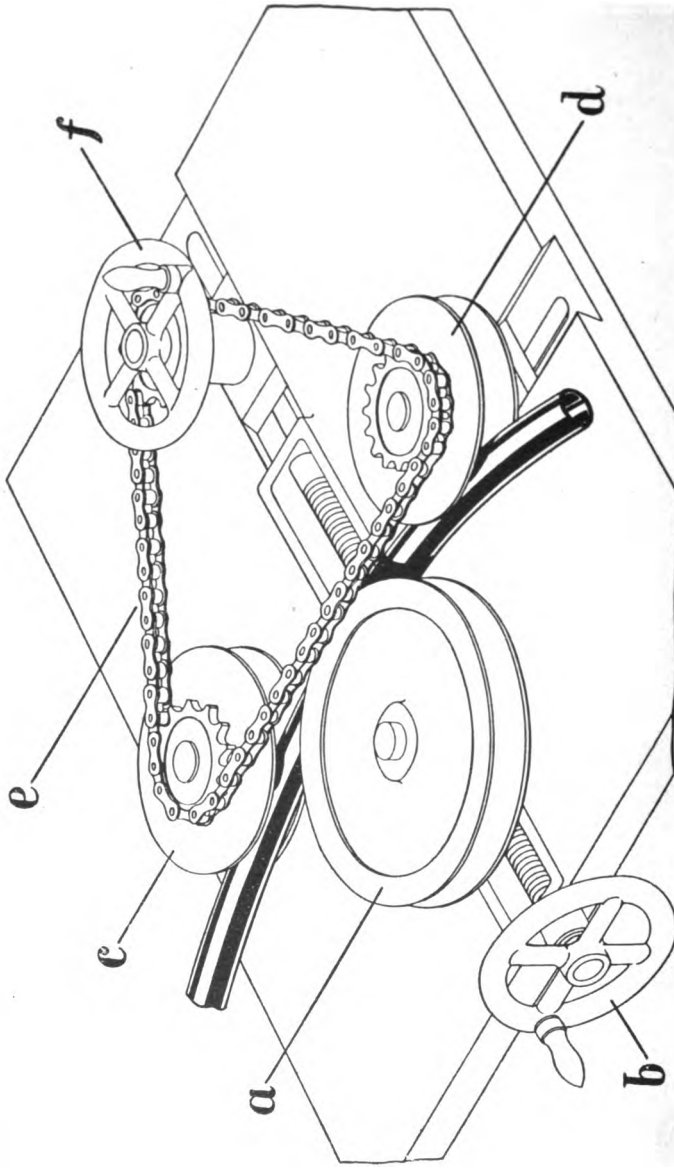


FIG. 1.—Tube-bending machine.

straight tube. The other pair (*c*) and (*d*) are then revolved first in a clockwise direction and then reversed; as the tube gradually takes up the pressure the same is increased, meanwhile the rotation of the loose rollers continues, according to the curve required. After the bend is completed, a slight loss on the diameter of the tube is discernible; but by careful rolling, however, this can be reduced to such a small amount as to become negligible. Should a slight kinking of the tube occur during this operation, the radius on the rollers should be adjusted until it is overcome. The ideal radius must be found by trial, and in this connection it might be as well to call the attention of the designers to the fact that practically every size and every thickness of tube bent to any particular radius required its own size of roller. The drawing-office should therefore endeavour to standardise both on sizes and radii of bends as far as possible.

The actual apparatus required for the cold bending of tubes is extremely simple. It consists of three cast-iron rollers turned out in the groove to a radius to suit the size of the tube to be bent. This radius corresponds very closely to the actual radius of the tube. From the exact centre line of the radius the sides are continued parallel for approximately half an inch. Particular mention is made of this point on account of its importance. Should it be omitted, there is great danger of causing damage and flattening of the tubes.

The roller (*a*) is mounted on a spindle which in turn is mounted on the square thread screw, by which the pressure is obtained, through the action of turning the handwheel (*b*). The rollers (*c*) and (*d*) are each mounted on a spindle, which in turn is secured to a sliding plate, which, having found the correct position relative to the curvature of the bend required, is clamped in position with a nut on the frame. The rollers (*c*) and (*d*) are revolved by means of the chain (*e*), being connected up to the sprockets on the handwheel (*f*) and rollers (*c*) and (*d*). The whole of this gear can be arranged between two suitable cast-iron plates fixed to a table or bench. These plates need not be of great strength in themselves, but the assembled frame should be capable of resisting very heavy strains.

It must be realised that this method of bending tubes can only be applied when the curvature of the bend is regular and of a fairly large radius. Smaller bends *must* be bent hot, which, in the case of tubes over $\frac{1}{2}$-in. diameter, invariably necessitates filling with sand, after which they are hammered to shape with a round-nosed hammer.

The next operation in the manufacture of the portion of the longeron is to cut it to the correct length, either square with the tube or with what is known as the fish-tailed end (see fig. 2)—this type of end is used on account of the increased periphery of the actual joint thereby obtained,

which is an important factor in the ultimate strength of the finished article. It is usually cut with a hack-saw and filed to the shape required, but more elaborate methods could be used if the number to be made warranted it.

The construction of the joint is quite obvious

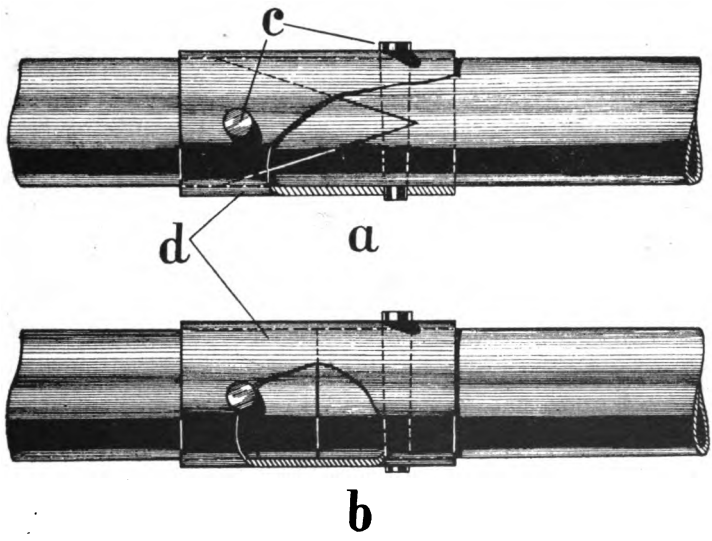


FIG. 2.—Steel tube joint.

upon reference to fig. 2. (*a*) shows the fish-tail type, and (*b*) an ordinary "butt"-ended joint. It is reinforced doubly, by first passing a collar (*d*) over it, and then driving the taper pins (*c*) into holes drilled and reamered out to suit. These pins are afterwards riveted over at the ends in order to ensure that they will not be shaken loose by vibration.

We can now turn our attention to what is rightly

regarded as the most important operation of all in the preparation of a unit of a steel tube body—namely, the "tinning" of the tubes in readiness for the sweating or soldering of the various units.

"Tinning," as its name implies, is the coating of the surface of the raw tube with a thin coat of "tin." The tube is first of all well cleaned by bathing in "killed spirits," and, after being well rubbed off with a cloth, is washed again in a strong soda water solution. The tube is then taken to the tinning shed and is again bathed on the outside with the "killed spirits" which form the flux. This flux should be applied hot with a ladle, and it is common practice to cover the whole surface and not merely the portion adjacent to the joint, on account of the necessity for preventing rust occurring on any portion of the member. The tube is then quickly transferred to the bath containing a solution of tin and lead, in equal parts, which is ladled on to it until the whole surface is well coated. It is then rubbed down with a cloth and transferred to the soda bath again, in order to negative the action of any small quantity of the "spirits" which may remain. Great care should be taken to ensure that the coating thus obtained is regular and clean. Several applications to the "spirits" may be necessary, in order to obtain the desired result.

The tinning of steel members of such a frame as that under discussion not only gives the results

mentioned, but also gives the job a thoroughly good appearance.

The remainder of the members of the frame may be prepared in a similar manner according to their separate requirements.

The next consideration is the jointing sockets.

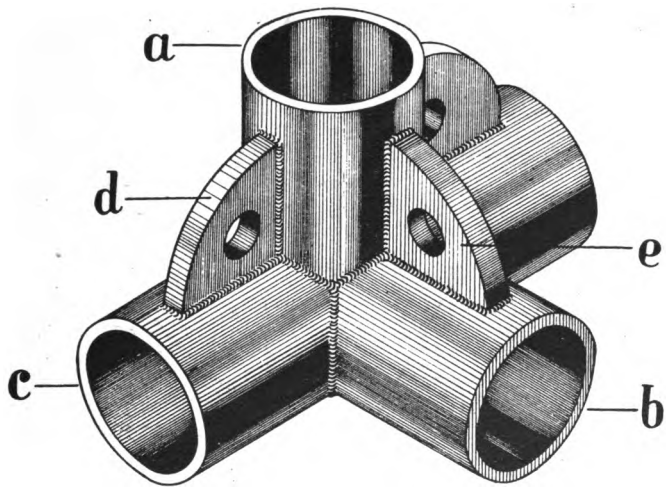


FIG. 3.—Built-up frame joint (welded).

These are designed to suit the angles of the various members, and are made either of steel plate or tube or both. Taking the socket illustrated (see fig. 3) as being typical of the practice followed throughout the frame, it will be seen that three pieces of tube (*a*), (*b*), and (*c*), are welded together with segments of plate (*d*) and (*e*) welded in the angles. The actual operations entailed involve the cutting off of the tubes and the shaping of their ends, the

cutting out of the pieces of plate to a template, and the welding of the parts together, after which the socket is tinned all over, as in the case of the longeron.

Of these operations the welding of the parts together is deserving of special mention.

The word "welding" is used to denote the uniting of the parts by means of a flame caused by the combustion of acetylene in oxygen. Uniting does not adequately describe the operation, as the effect of the application of the flame to two pieces of steel held edge to edge is to fuse them, forming a joint composed of the same constituents as the pieces themselves, and which is in many cases, if carried out properly, as strong. In other words, the heat causes the metals to melt and flow together. That this is so will be more readily realised when it is noted that the temperature of the flame is in the region of 6000° Fahr. at its tip, this being the actual portion of the flame used during the operation. Acetylene is a compound gas that gives out heat when it is decomposed. Together with the oxygen under pressure, it is applied for welding by means of a blowpipe (see fig. 4), having a tip (*a*) screwed on to the tube (*b*). Tips are made with different-sized outlets so that they can be varied according to the class of work in hand. The flame must first of all be adjusted until a neutral flame is secured. This neutral flame is easily discernible by its colour, which is a shade darker than the flame surrounding

it. Care must be taken in opening the valve of the oxygen cylinder (*c*) to the required pressure, which varies according to the size of jet used. Then, taking the blowpipe in one hand and a piece of Swedish iron wire in the other, apply the flame

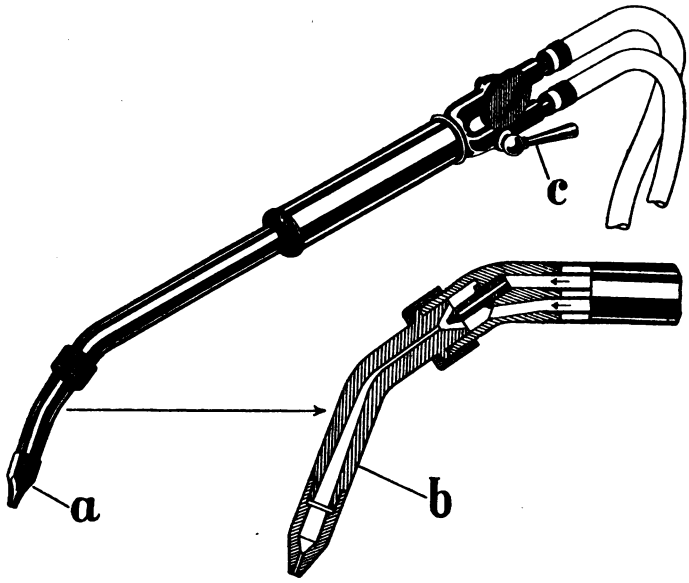


FIG. 4.—Welding blowpipe.

until the adjacent metals are molten and flow together. During the operation the eyes must be protected from the rays of the flame by means of a darkened glass, either blue or green. All blowpipes are provided with special chambers to prevent back fire, and should have also independent control on the acetylene gas. Acetylene gas is generated by bringing calcium carbide into contact with water

in a special container or generator. The most popular type of generator is one having a number of separate compartments which are exposed to the water in turn, thereby preventing excessive heat by the generation of a large quantity of gas at a time, also ensuring a clean or pure flame. In order to ascertain whether the carbide is exhausted, most generators are fitted with an indication tap. When this is turned on, should gas flow the carbide is not exhausted, but should water flow the reverse is the case. Before the gas generated leaves the container, it passes through a filter consisting of cotton-wool or similar material, in order to remove all impurities. The effect on the weld, should this precaution be omitted, would be a small stream of lime deposited on the point of application, with the result that the weld would be weakened. Other impurities such as ammonia, phosphorus, etc., are removed by passing the gas containing them through water. Where the work is of an extremely fine nature, or where the obtaining of acetylene from calcium carbide is a matter of difficulty, dissolved acetylene in cylinders should be used.

The most important point in the actual application of the flame to steel plate is to ensure that the flame is directed in a horizontal rather than a vertical direction, this angle being increased from the horizontal towards the vertical as the thickness of the plate increases.

The welder should always have a supply of clean

water at hand, as it is necessary to occasionally dip the tip of the blowpipe in it. The necessity for this precaution becomes obvious when the temperature of the flame is considered, viz. 6000° Fahr.

All welded joints should be thoroughly annealed. This operation consists of placing the fitting in a muffle and heating to a bright red colour, then allowing to cool off in the air. This prevents the formation of excessive stresses in the texture of the metal. It must not be imagined that the foregoing explanation of welding will enable the student to take up a blowpipe and make a perfect weld at the first attempt. Much depends on the actual handling of the pipe by the welder. Proficiency can only be obtained by practice and careful consideration of the principles involved.

Tie-rods (see fig. 5) are the rods used for bracing the frame members together. They consist of an extremely strong steel rod, screwed at each end to take suitable end fittings, one type of which is shown in fig. 5, and having a square milled on for turning by, when adjustments are required. They are usually swaged or rolled to a diameter equal to that of the roots of the thread, thus having a constant effective diameter all along their length.

The general construction of a tie-rod can be seen in fig. 5. The rod itself (h) is screwed at each end (g) and (g_1), the total length being so arranged that a fair amount of it enters the fork end when in

position, and also a sufficient portion remains outside the shank of the fork end for adjustment. The upper view shows the "fork end" (*a*) which slides on to a fuselage wiring plate shown dotted.

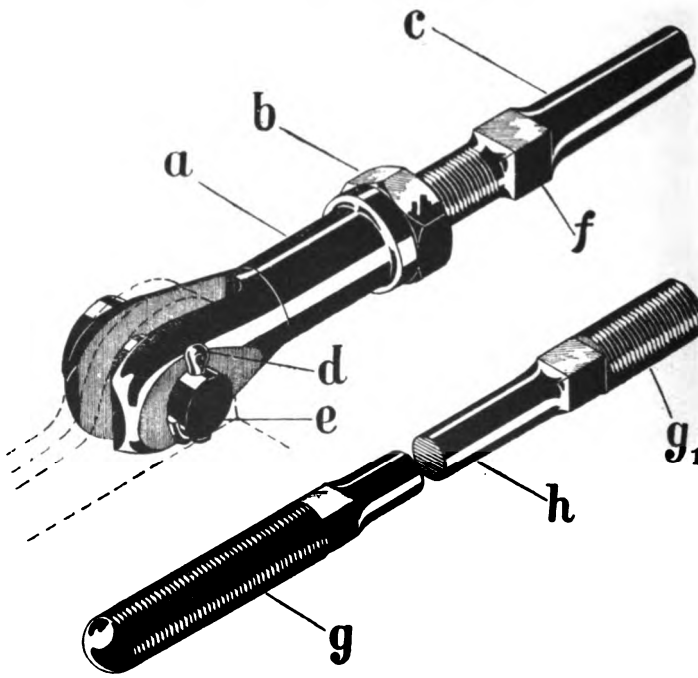


FIG. 5.—Tie-rod.

A "lock nut" (*b*) is provided to jam it in position when adjusted. The tie-rod itself (*c*) is screwed into position by using a spanner on the squared portion (*f*). The fork end is held in position by the pin (*e*), which in turn is fixed by the split pin (*d*). The fork end is sometimes replaced by an eyebolt if the design of the wiring plate is such

that it provides two jaws instead of one as shown here.

In dealing with experimental machines of which only small numbers are being built, piano-wire bracing is often used instead of tie-rods. Fig. 6 shows a typical method of making an end in this case. The wire (*a*) is passed through the hole in

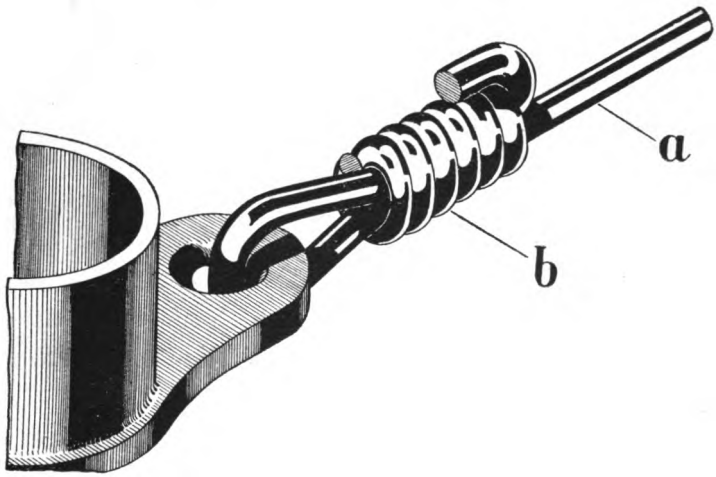


FIG. 6.—Piano-wire bracing.

the wiring plate and doubled back, passing through a ferrule (*b*). It is then made tight by bending back over the ferrule.

The remainder of the parts required for a steel frame are constructed in a similar manner to those already described. It will now be a good opportunity to consider the assembly of them. First of all, lay the parts for the top and bottom portions on a wooden jig or table, having the positions of the

various members marked on its surface; then, having found the correct position for each socket, thread them on to the longeron in the required order until this is reached. It is here as well to mention the importance of designing the sockets for the front curved members so that they are allowed to slide around the curved portion of the tube. This can be arranged for by allowing rather more clearance between the socket and the tube at this point than elsewhere. Then, having checked the various positions carefully, drill holes through the socket and tube, and insert the taper pins. Repeat this operation around the whole framework, put the cross members in position, and it is ready for sweating. This is actually the soldering of the tubes and sockets together, which is done in a similar manner to the soldering of joints described in the paragraph on tanks.

It is essential that the solder should reach every portion of the faces to be combined, with a frame of the type described. The best way to ensure that this is done is to stand the frame on end against a trestle or bench, placing a small quantity of flux round the top of the socket, then applying heat to its entire surface.

If the inner face of the socket and the outer face of the tube have previously been well tinned, *i.e.* well coated with solder and tin, no difficulty should arise, and a good metallic joint will be secured. Having followed this out for all of the sockets on

the top and bottom longerons, next place the upright and diagonal members in position, which are then pinned and sweated as before.

The frame is next braced by placing the tie-rods in position and tightening as required.

Every steel frame has its particular variations. These must be dealt with as they arise. For instance, some designers favour brazing—this is not generally used on aircraft, but, being an extremely efficient and economical joint, it is deserving of special mention.

Brazing consists of hard soldering the faces of the two pieces of metal together by means of a brass spelter. This spelter or solder is somewhat difficult to make, owing to the importance of casting at the proper heat. However, experts having taken its manufacture up in quantity, it is now easily obtainable in a number of different grades of coarseness, the important point in the selection of any particular grade being that it should melt at a heat slightly lower than the metals it is desired to unite. The importance of this cannot be overestimated, as, should any great difference occur in the melting temperature of the spelter and the metals to be joined, cracks will develop as a result, this being chiefly due to the unequal rate of contraction when cooling.

As in the case of ordinary soldering, a flux is necessary, the most efficient and, at the same time, the most common one being ordinary borax.

The actual process consists of, first of all, cleaning the metals thoroughly with a file and then with a sand blast (see fig. 7). The parts are then bound together with a piece of wire and the flux, mixed with water, smeared round the required joint, which should then be heated in order to get rid of the moisture. The part is then heated to a white heat, and the spelter, after having been mixed with the flux, applied. The heat must be maintained until the spelter is seen to flow, when the heat can be removed and a perfectly brazed joint should be the result. Failure in this can be ascribed generally to two causes—namely, insufficient heat and greasy or dirty surfaces.

The type of blowpipe used must have a separate control for the gas as well as air, in order that the flame may be regulated to suit the work in hand.

Lamps are sometimes used for brazing, burning benzoline or paraffin under air pressure; but at their best they are a poor substitute for a blowpipe fitted to a gas line and air compressor.

Another method of brazing is that known as "liquid brazing," the advantages of which are seldom utilised to the extent they deserve. Its operation is the same in principle as ordinary brazing, but the saving in time by its use makes it a necessity where large quantities of parts are required to be brazed. First of all, half fill a suitable crucible with what has become known as

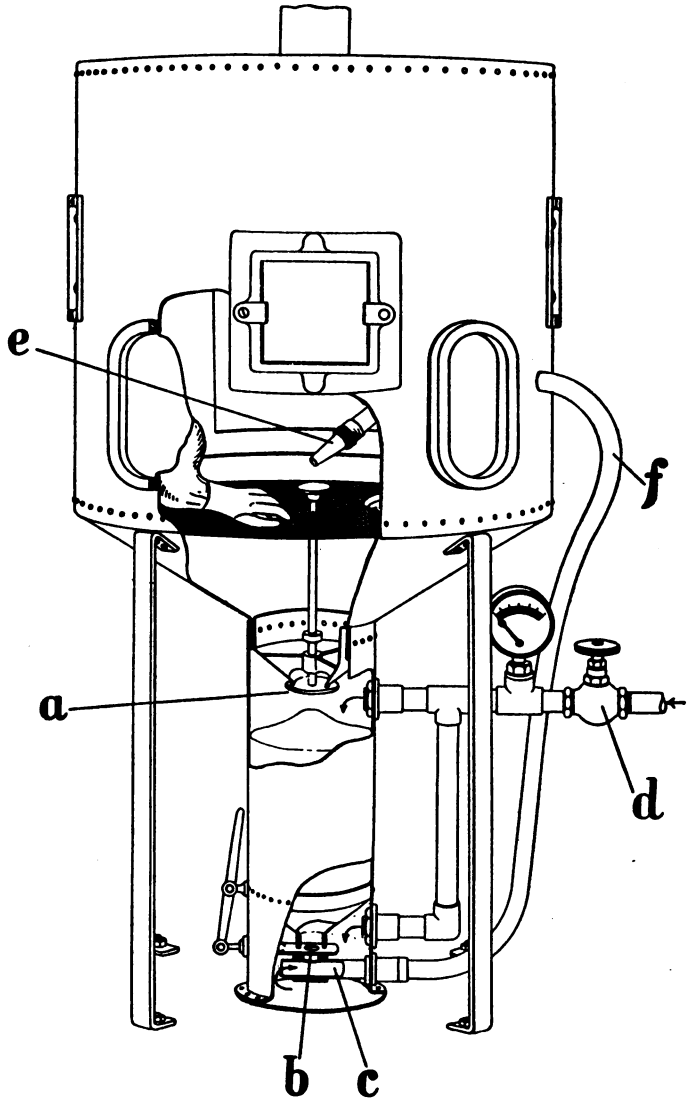


FIG. 7.—Tilghman's sand blast.

"Chillies" or small pieces of brass turnings, then melt the same over a coke or gas fire.

The surface of the molten metal must then be covered with borax, until a skin approximately ¼ in. thick is obtained, molten, on the surface of the metal. This skin should be slightly lighter in colour than the molten brass beneath. Its thickness can be gauged by breaking through with a piece of iron or steel. An examination of the skin thus obtained will prove that the borax in the immediate vicinity of the point of entry has attached itself to the surface of the steel.

The fittings having been coated with carbon wherever the brazing is not desired, they are slowly immersed in the molten brass for a period long enough to enable same to run cleanly through the joint desired when the steel has reached the required temperature.

The preparation of the parts to be brazed is important, and should be done in the following manner. First of all, prepare a paste of ordinary treacle and blacklead, then coat the parts of the metal at which brass is *not* required, using a brush. Then heat the part until all the moisture evaporates, thereby depositing a thin layer of carbon on the surfaces of the metal.

Liquid brazing has the advantage that no preliminary cleaning of the joint is necessary. The flux, being at a temperature equal to the molten brass, is sufficient to penetrate and displace all

impurities on the surface of the metals to be joined.

Considering that the average time of immersion required to braze most of the fittings used on aircraft is well under one minute, it is surprising that a great use is not made of this system of brazing, the joint obtained being infinitely superior to the joint obtained by ordinary brazing.

Another important advantage is the fact that it is possible by this method to braze slightly oxidised metals. This fact can be utilised when the joining of the parts to be brazed together is under consideration. Instead of wiring them they can be spot welded, which in itself is a time-saving device, consisting of lightly welding the two parts together at one or more points on their edges.

After brazing has taken place, it is necessary to clean the joint well, as the brass spelter does not flow evenly, the result being that a layer of hard brass is left. This is not only unsightly, but adds additional weight to the part. The cleaning of the joint is done by sand blasting (see fig. 7). This consists of directing a stream of fine hard sand on the surface of the metal at a pressure which varies according to the requirements of the part.

The action of this plant is as follows. The air under pressure acts directly on the upper surface of the sand in the hopper (*a*) and also on that portion of the sand exposed at the lower orifice (*b*). The combined effect of these opposing pressures is

to enable the sand to gravitate by its own weight into the air channel (*c*). The air under pressure in the container, when the necessary valves (*d*) are turned on, at once finds its way through the air channel, carrying with it the desired quantity of sand, ultimately escaping from a reduced nozzle (*e*); the stream of sand can be easily directed to any position by reason of the flexible connecting pipe (*f*).

The utilisation of steel is often attended with a corresponding increase in the weight and cost of the framework obtained as compared with other materials. It is, therefore, necessary to ensure that superfluous metal on the various parts is reduced to a minimum.

In addition, the labour entailed in working the parts should be considered. For instance, it may be necessary on the score of strength to make a fitting $\frac{1}{4}$ in. thick. It does not follow that the part should be made from a single plate of that thickness, as two plates having an equivalent thickness joined together by brazing, soldering, or edge welding are known to be very much stronger, besides being very much more easily worked to the required shape. This is more often apparent in the case of parts used for bracing purposes in main planes, where the designer, in his efforts to economise in weight, designed a fitting of extremely complicated outlines, such as is shown in fig. 8.

It is obviously imperative that, wherever a

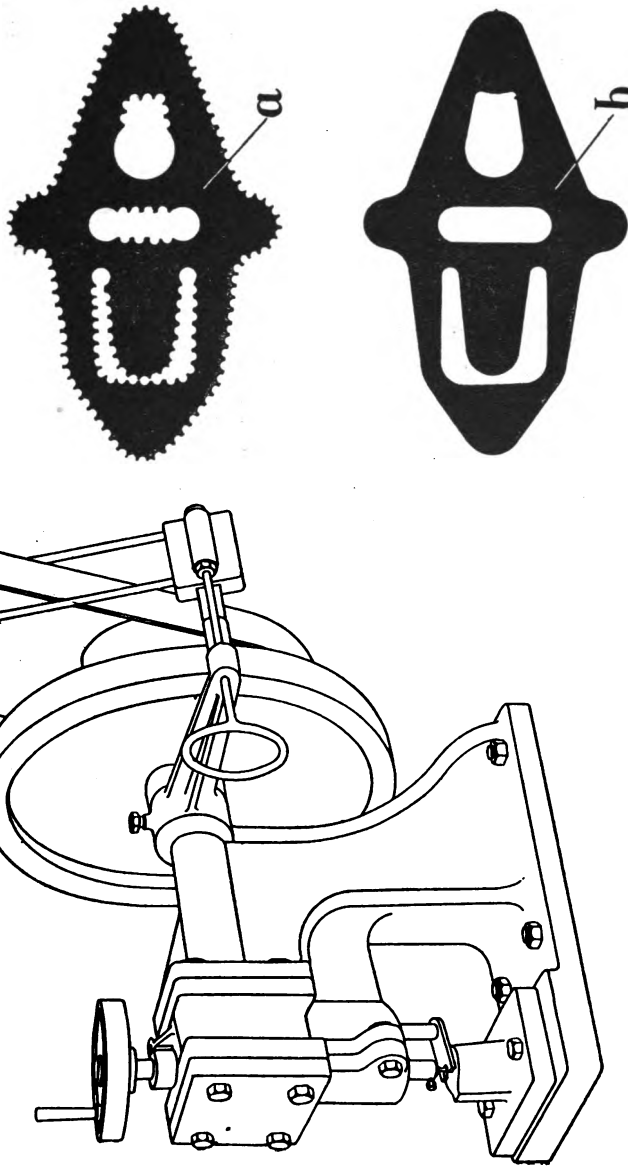


FIG. 8.—Nibbler.

number of fittings similar to that shown in fig. 8 are required, each performing a similar operation, they should be as far as possible of the same shape, even at the expense of appearance and weight. Sufficient attention is seldom given to this point, the result being that expense is incurred unnecessarily, first of all in the designing, then in the manufacture of the various tools, templates, and gauges required to make the part.

Wherever it is not feasible to utilise press tools, the making of a fitting similar to that shown in fig. 8 would need to be as follows:—

Transfer the shape of the part to the sheet metal of the required thickness; then, either with a hammer and chisel, or preferably with a nibbling machine, cut around the lines, as shown at (*a*), then trim up with a file to the shape at (*b*).

The holes, if any are required, can then be drilled, taking care to place the hole accurately, thereby ensuring a uniform amount of metal around it to withstand the strain to which it will be finally subjected.

The "Nibbler" (see fig. 8) is a machine designed especially for this class of work, and consists of a cast-iron body having an extremely deep throat horizontally. In the end of this a slide is arranged to work in vertical direction. In this slide a tool is carried which, when the machine is in motion, slots or nibbles its way through the plate. A roller feed beneath is of great advantage in

manœuvring the sheet of metal in the required direction.

The bolts and nuts for securing the metal members of an aeroplane have received a good deal of attention. This culminated some years ago

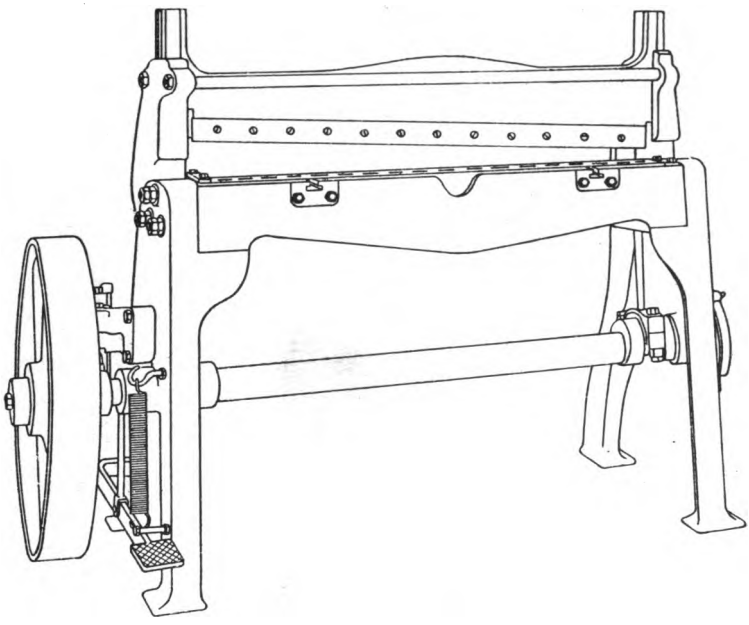


FIG. 9.—Guillotine.

in the issue of what is now an approved standard known as A.G.S. This has been arranged in the form of tables setting out the various numbers or letters with their equivalent sizes. For instance, a "B.S.F. thread (British Standard Fine) bolt, $1\frac{1}{2}$ in. long," might be called "A.G.S.103.E."

This practice, which is already widely carried

out, is capable of extension to almost any part which is likely to recur.

In addition to the special plant already mentioned, the following tools are commonly used in the manufacture of steel fittings for aircraft: cold chisels, files, vices, guillotines, hack-saws, drilling machines, and grinding machines.

The first three are only used where either superfluous metal has to be removed or the fitting has to be made entirely by hand, press tools not being available. Hack-saws and grinding machines may also be used. Of the remainder, the guillotine is perhaps the most largely used (see fig. 9). It consists of a pair of hardened steel blades carried in a cast-iron frame, the vertical blade being carried on a slide. When the foot-treadle is pressed, this blade descends and shears the metal which lies on the table. The latter also carries a blade, similar to the one on the slide, which completes the cutting operation.

CHAPTER II

PRESS TOOLS: THEIR SELECTION AND APPLICATION TO AIRCRAFT PARTS

PRESS tools can roughly be divided into six classes, each of which has its particular application to the manufacture of parts used on aircraft.

These divisions are roughly as follows:—

(1) Blanking tools.
(2) Piercing tools.
(3) Combined blanking and piercing tools.
(4) Forming tools.
(5) Combined blanking and forming tools.
(6) Bending dies.

Indiscriminate use of press tools in the manufacture of aircraft fittings should be avoided, as the underlying principle of their application is thereby often defeated.

This principle is "reduction in the cost of production." Other considerations enter into the subject, such as "interchangeability of parts," "accuracy of manufacture," and the necessity for increased output; but these should not be confused when a discussion takes place as to the

advisability of adopting a particular method of making certain fittings.

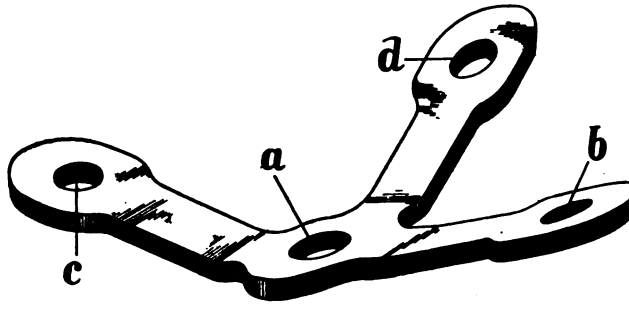


FIG. 10.—Wiring plate.

In order to thoroughly appreciate the foregoing, take a few typical examples of metal parts or fittings used in the construction of the wings and body of an aeroplane (see figs. 10–13).

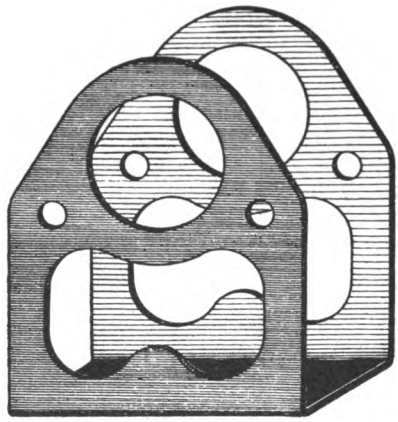


FIG. 11.—Spar box.

Considering the wiring plate (fig. 10), this is a typical example of the type of fitting used for bracing the members of the fuselage or body of an aeroplane, the lugs (*b*) and (*c*) taking the diagonal wire between the struts and the lug (*d*) taking the cross wire.

First of all, consider the cost of a blanking tool

for pressing or stamping (as it is often known) this out, estimate the quantity likely to be made, and set this down against the cost of making the blank by hand with the assistance of such machines as

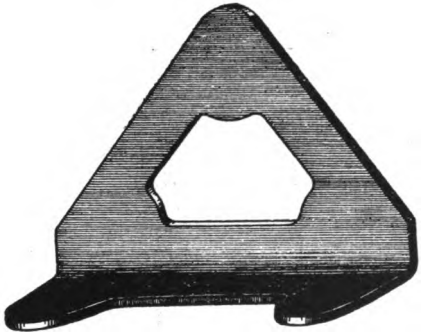


FIG. 12.—Support.

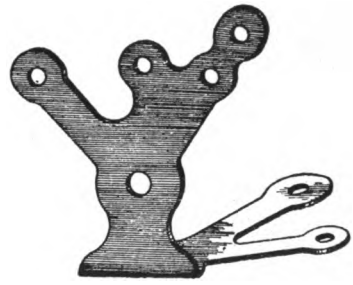


FIG. 13.—Wiring plate.

"shears," etc. The results of these considerations should then be compiled as follows:—

	Tools.	Hand.
Cost of tool (say)	£8 0 0	
Quantity of pressings to be made, 100.		
Cost of pressing 100	1 0 0	
Cost of cutting blank by hand, 100 .	...	£17 0 0
	£9 0 0	£17 0 0

Net saving by use of press tools = £8.

These figures will, of course, vary according to the type of fitting; but in the case of results such as the above being arrived at there is not the slightest doubt as to the advisability of adopting the press tool.

For the sake of argument let us take the same fitting, and assume that there are only ten required, and we have :—

	Tools.	Hand.
Cost of tool	£8 0 0	
Cost of pressing 10 from tool . .	0 2 0	
Cost of cutting 10 by hand . .	...	£2 14 0
	£8 2 0	£2 14 0

It becomes apparent in this case that a press tool should not be adopted.

Assuming that it is decided to make a press tool, the first step is to make a "template" which is an exact replica of the part required, with the exception that it is flat instead of bent, as is the case with the fitting shown in fig. 10.

Then determine the weight required to blank this part out; this is done as follows :—

Periphery of the blank in inches, multiplied by the thickness in inches, multiplied by the shearing strength of the metal—in this case steel plate, the shearing strength of which can be taken as 22 tons per sq. in.

Assume periphery to be 9 in.,
,, thickness ,, $\frac{1}{8}$ in.,
and we have

$$9 \times \tfrac{1}{8} \times 22 = 24\tfrac{3}{4} \text{ tons.}$$

This gives the weight required to press the fitting,

and, having selected the press accordingly, the die or tool can be made to suit the particular machine. A

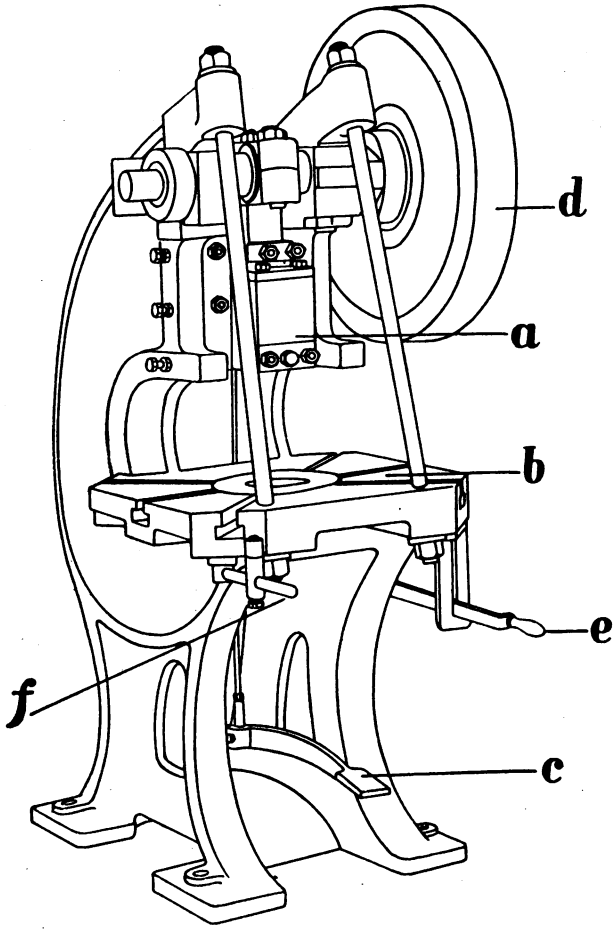


FIG. 14.—Press.

typical power press is shown in fig. 14. The ram of the press (*a*) which carries the punch is given a steady vertical movement by the cranked axle

attached to the heavy flywheel (*d*). The bolster carrying the die and other parts as necessary is fixed to the table (*b*). The machine is controlled by the operator's foot, which actuates the lever (*c*). Extra handles are provided at (*e*) and (*f*) which are used instead of (*c*) for working the machine under certain conditions. When the article to be stamped is of simple form, the die is so arranged that the stamped blank falls through, and if the pedal at (*c*) is used the operator has both hands free to control the feeding of the metal bar into the machine. It often happens, however, that the work is of such a shape that it has to be pressed into a hollow saucer-shaped die, and then lifted out of the die after the punch has ascended. In this case the handles (*e*) and (*f*) are used instead of (*c*). These two handles are interlocked and so arranged that the pressed article can only be removed while the punch is stationary at the top of its travel. By this device all possibility of the operator endeavouring to remove the pressing while the punch is descending and having his hand crushed is avoided, as the machine is out of action as soon as he leaves go of either (*e*) or (*f*).

The press tool consists of three parts, omitting various parts such as bolts and screws, etc. (see fig. 15).

The punch is shown at (*a*). The die (*b*) is held in the bolster (*c*) by the taper on its two opposite edges, which slide into a taper slot (*d*) in the

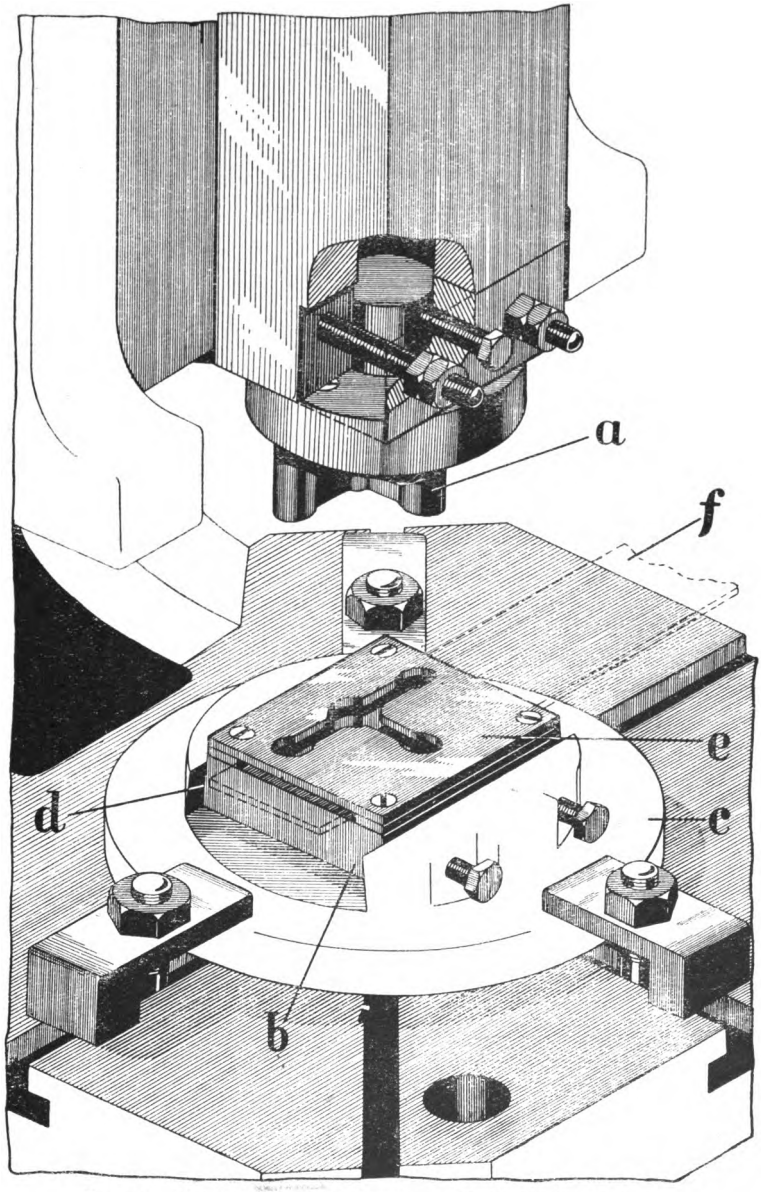


FIG. 15.—Typical press tool, showing method of fixing to press.

bolster. (*e*) is known as a stripper, its function being to prevent the metal bar (*f*), which is pierced by the descending punch, from jamming itself on to the punch and rising with it. The method of attaching the punch to the ram of the machine, and also the bolster to the table, can be seen on this diagram also.

Referring to fig. 15, it will be seen that, having made the tool, it is possible at a single blow of the punch to stamp or press out of a sheet or strip of the metal used the required fitting.

The metal in strip form is placed between the stripper and the die. The machine is then started, and the punch descends sharply, passing through first the gap in the stripper, then the metal, and finally the die to a depth approx. $\frac{1}{64}$ in. greater than the thickness of the metal. The punch then reverses and travels to its original position, where it remains stationary until the next stroke is made.

The pierced blank of metal falls through the hole in the die, the hole in the latter being cut away to a rapid taper (see fig. 20) to allow for this.

We have now a blank of the fitting required, which has to be passed on for the next operation, in this case making the necessary holes and bending.

In order to obviate the drilling, should the quantity to be dealt with allow, a piercing tool is made in a similar manner to the tool described above, with the exception that punches are arranged

according to the position and size of the hole required. It is necessary to bear in mind the fact that in aircraft fittings it is not always advisable to punch holes owing to the danger of damage occurring to the texture of the metal punched, and the consequent risk of failure when in use.

The only way of ensuring that this weakness does not exist is to remove a thin layer of the damaged metal from the circumference of each hole by reamering. This, however, introduces the disadvantage of an extra operation on each blank, which in most cases makes the operation of producing the finished hole more laborious and costly than by drilling it in the first instance.

Combined piercing and blanking tools are also arranged in a similar manner to that already described. The fittings shown in figs. 11 and 12 are suitable ones for their use, the cutting out of the holes by hand in order to save weight being an expensive and slow operation.

The next operation to consider is the use of forming tools. These are most commonly used in the manufacture of the ends and baffles (see Tanks) of petrol, oil, and water tanks, and are often constructed in the manner shown in fig. 16.

There are several classes of forming dies, including plain drawing dies, combination dies, double-action dies and triple-action dies.

In the case of the die illustrated in fig. 16, a simple-forming die for a tank end is shown. The

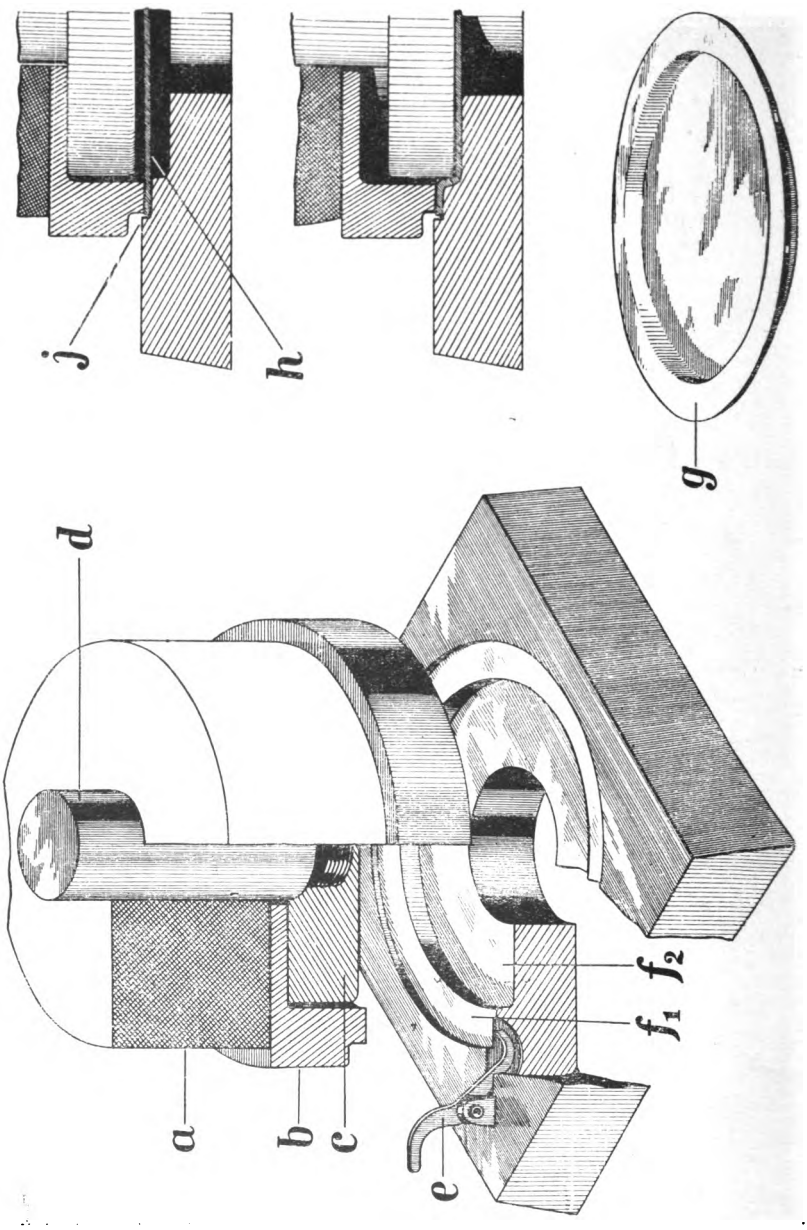


FIG. 16.—Drawing die for single-action press.

blank of the tank end is first either cut out by hand, using tinmen's snips or scissors, or blanked out in an ordinary blanking die. This is not necessarily a big saving in labour or time, as the blank in this case may be merely rectangular with sufficient material left on to hold by when forming.

The blank (*h*) is laid in the die in the location (*j*) provided, the clutch of the press is then engaged, the punch (*d*) descends, and the blank holder (*b*) grips the blank against the face (f_1) of the die. The punch meanwhile continues to the depth required, compressing the rubber (*a*) until the former (*c*) has forced the metal down on to the face (f_2) of the die, thus forming the edge of the blank to the depth required.

The two independent operations in this action are shown in the enlarged views in fig. 16, the finished article being shown also at (*g*). Great care should be taken to ensure that all corners of the die actually coming into contact with the metal are smooth, and have sufficient radius on them to allow the metal to flow evenly. This radius should be at least equal to the thickness of the metal being formed. If this is omitted, the formed edge will be badly grooved and possibly torn at these points. The blank is now removed from the die, the punch having ascended, by using the extractor (*e*).

Some dies made on this principle are fitted with a strong spring instead of a rubber buffer at (*a*).

Rubber, however, is preferable, as it takes up the shock of the descending punch more gradually, and consequently there is less risk of distortion and cracking of the metal.

The combination type of die is one in which a blanking die and either a drawing or forming die are combined, so that the blank is cut out and driven or formed to shape in one stroke of the press.

In the case of the die just described, it is a design of tool specially adapted for use with a single-acting press.

When a double-action press is available, the die is very much simpler. These dies are known as double-action type, because the blanking and forming punches have independent movements which are derived from the two slides of a double-action press, hence the name of the die usually denotes the type of press for which it is intended.

Bending dies are arranged in a similar manner to that shown in fig. 17.

In this case the ram carries a block shaped to suit the bend required (*a*, *b*). A die (*c*) similarly shaped is fitted to the bolster. The two operations of gripping the blank in the location (*d*) and bending it to shape (*e*) are shown on this drawing.

Trouble is sometimes experienced with this type of pressing, owing to the fact that the bent blank tends to straighten out slightly after the pressure of the top block is removed. In order to obtain

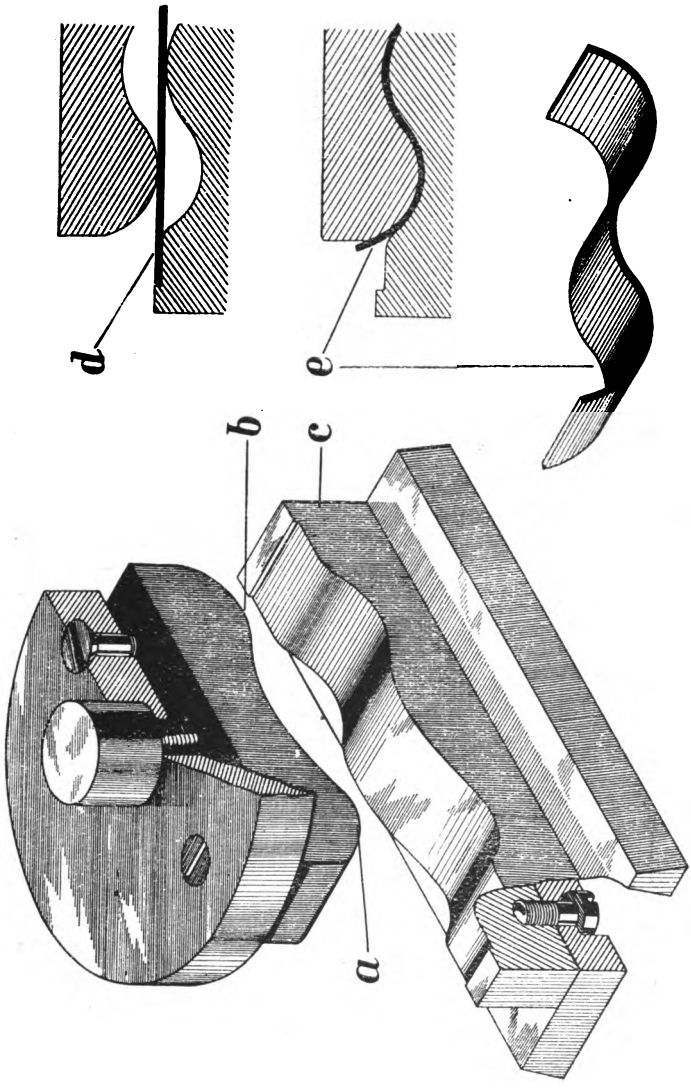


FIG. 17.—Bending die.

the correct shape on the finished article, the block and die must be made with rather more curvature. The amount to allow must be a matter of experience, depending as it does upon both the radius of the curve and the natural resilience of the metal being pressed.

The dies used to form beads around cylindrical parts are a form of bending die, although not in as common use.

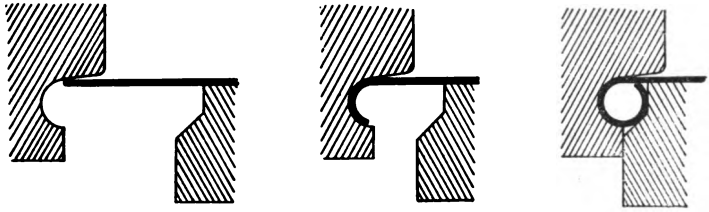
A beading die for the upper edge of a cover for controls or tank cap is shown in fig. 18.

The punch has a centre piece (*a*), which is the exact size of the work, and it is also provided with a semicircular groove (*b*) which, when in contact with the cap, causes the edge to turn over as indicated. This can only be done with comparatively thin metals. A die of this type must have an ejector fitted similar to that shown in fig. 16 in order to remove the work from the die after the edge is beaded. The action which takes place during the descent of the punch is clearly shown in the enlarged details.

There are, of course, a hundred and one variations possible to the types of die described, but these outline roughly the principles of all.

When manufacturing a die, the amount of time and care spent in preparing it depends upon the quantity of parts to be made. In the case of the fitting shown in fig. 10, the die for this would be expected to stand up to practically any protracted

period of working, and it should be capable of being repaired or sharpened with ease.



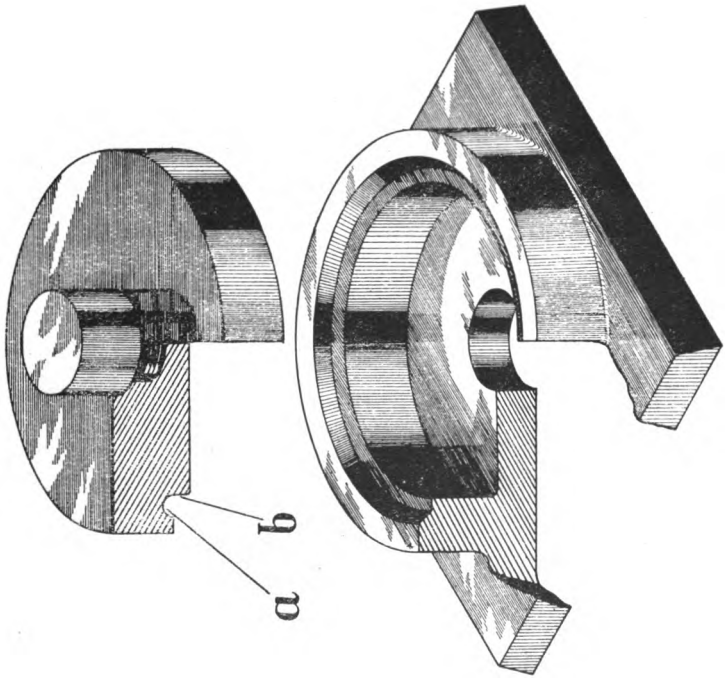


FIG. 18.—Bearing die.

A die of this type made on the lines shown in fig. 19 must be of the very highest grade of

materials, and the workmanship of the finest standard. This die is taken as an example, because almost all the parts used on an aeroplane requiring blanking are either of this type or very similar to it.

The first step is to select a piece of tool steel. This must, as mentioned before, be of the best quality, and of sufficient length, width, and thickness to enable the die to withstand the pressure exerted when cutting the blank. Then proceed with the making of a template that conforms to the shape of the blank required, care being taken to allow for the bend. The template, usually made of sheet steel, must be accurate and well finished on its edges. The addition of a handle soldered to it is a great convenience for handling it during use. A template must, of course, consist of two parts, male and female, the male being used when cutting out the die, and the female when shaping the punch.

The first operation on the die is to machine all the faces of the piece of steel and shape the edges to fit the bolster, which is usually dovetailed as shown in fig. 19. The top surface should then be thoroughly smoothed off and polished, then coppered over with copper sulphate in order to render the surface suitable for marking on. The template or, as it is sometimes known, the master blank is then laid on the prepared surface and clamped. By following the outline of the template with a sharp scriber, its shape is transferred to the face. An

important point to bear in mind here is that before doing this it is necessary to first of all determine the most economical way of cutting the blanks, the idea being to obtain the greatest number of blanks from any particular standard size of sheet metal to be used.

After the die has been marked out, the next step is to machine the hole for the punch. The fitting

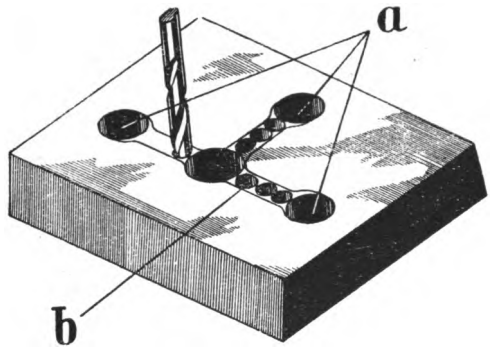


FIG. 19.—Removing stock by drilling.

which has been selected as an example has round ends, and the best way to do this will be to set it up in a lathe and bore accurately the holes which will correspond to the shape of the lug ends (*a*). The remainder of the core can then be removed, by first of all drilling a number of small holes (*b*) through it, well inside the lines and as closely together as possible, then breaking down the metal left with chisel, and finally machining close to the lines by slotting or milling. The method of drilling out a die core is clearly shown in fig. 19.

If a chisel is resorted to, the chisel should always be driven away from the top of the die, as there is danger, when chipping from the other direction, of the metal fracturing outside the line and thereby spoiling the whole article.

Many special machines have been designed for cutting out dies; these should always be used when available, as a more uniform edge is obtained by their use than is the case when the die is cut out by hand.

When machining the hole in the die, the question

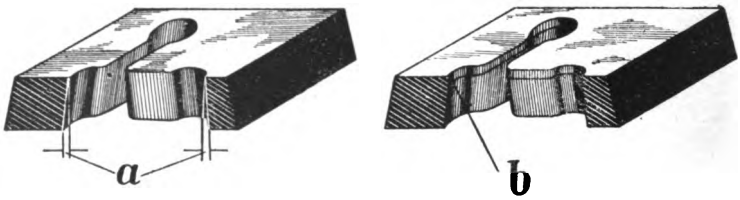


FIG. 20.—Angular clearance.

of angular clearance must be considered (see fig. 20). There are two methods of obtaining this: one is by cutting the sides at an angle of from 2° to 5°, shown at (*a*), clear to the top face; the other is by cutting the face at the same angle to within about $\frac{1}{8}$ in. of the top face (*b*). This should not be done, however, until all the surplus core has been removed and the die is ready for the finishing off.

This is usually done by filing, the die being secured in the vice, as in fig. 21, with its face toward the back of the vice; the hole is then filed until it fits the master blank, the master blank or

template being frequently offered up to the hole, and the bearing points marked with a pencil. This must be repeated until the hole fits the template perfectly and is just large enough to allow it to pass through; a piece of white paper placed behind the die during each offering of the template will prove of assistance to the sight.

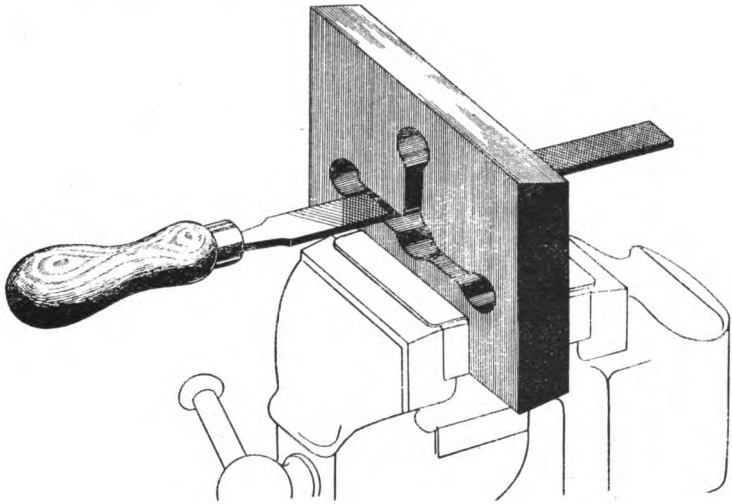


FIG. 21.—Filing a die.

It is essential that the clearance in the die should be as straight as possible in order to allow the blanks to fall easily through the opening when the die is in use. This requires considerable practice to attain, the beginner doing this usually getting a rocking motion on the file. Before any degree of proficiency is attained, he must first of all learn the art of regulating the pressure on each end of the file according to the distance of the ends from the

actual cutting teeth of the file. It is also usual to check the surface by offering up a small "square" made to the required angle from steel plate.

The clearance between the punch and the die should be regulated according to thickness and kind of material to be punched; the exact dimension for this can be obtained by dividing the thickness of the metal by the "constant" of the metal. For example, the clearance when punching 16 G steel should be

$$\cdot 06 \text{ in.} \div 20 = \cdot 003 \text{ in.} = \text{clearance},$$

20 being the constant known.

This figure, which varies for different classes of metals, has been arrived at as a result of experience in dealing with this class of work.

The experienced die-maker would probably vary this slightly according to the size of blank and the quantity of them required.

The die is now ready for hardening, and is accordingly placed in a gas muffle to "soak."

The word "soak" is used to denote the difference between uniform and irregular heating—in fact the secret of hardening steel consists in getting it as nearly as possible a uniform heat.

The ideal temperature for hardening steel varies according to the amount of carbon in the steel.

A rule which in the writer's experience has never been known to fail is, "The ideal hardening temperature is the temperature at which the steel loses its power of attraction, that is to say, its

magnetic properties," the only point to exercise judgment on being the length of time the steel is kept at this heat. Practically all pyrometers used in determining muffle temperatures have a line calibrated in red, to enable the ideal temperature to be easily observed. Should a pyrometer not be available, a magnet is a useful substitute, provided pieces of steel and tools such as tongs and trays are not lying about in the vicinity, as they will exercise an attraction on the magnet. Having obtained the required heat, lower the steel die into a bath of tepid salt water to cool. The die should next be prepared for tempering by polishing its face. The tempering is carried out by heating until the polished face turns to a deep straw colour and then cooling off in a bath. It is then ground until a keen and level cutting edge is obtained. The die being finished, attention can now be turned to the punch. The operations on this follow closely those already described for the die, with the exception, of course, that the female template is used. The surplus stock having been removed by filing or milling, it should then be chamfered slightly, so that its face will just enter the die. The remaining material is then removed by filing, care being taken to apply the punch to the die as progress is made, until it passes through, with a good but easy fit according to the clearance required. Having put a good surface on its sides and face by filing, the punch (*b*) is next drilled for the securing screws (*c*) and the

locating pins (*d*). The holes are tapped to take the securing screws (*c*), which hold it to the adaptor (*a*) (see fig. 22). These holes should be plugged with clay or other pliable heat-absorbing material, and it is ready for hardening. This is done in a similar manner to that already described for the die.

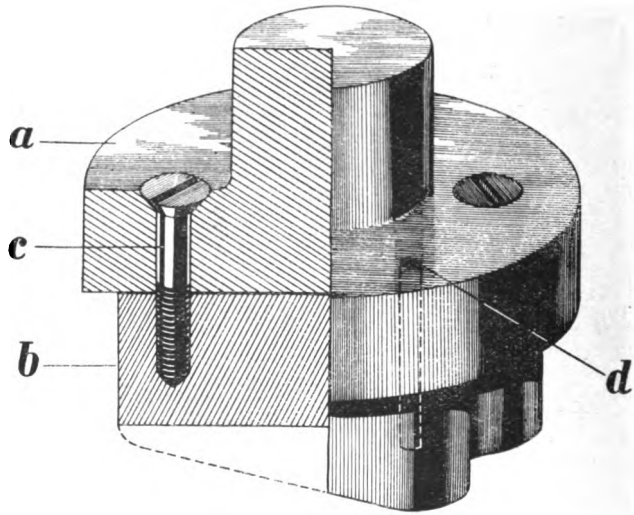


FIG. 22.—Section of typical punch and its adaptor.

Punches are attached to their adaptors or holders in a variety of ways. The method shown in fig. 22 is generally used for light work. The adaptor is made solid with its shank, which fits and is secured into the ram of the press by set screws. The personal ideas of the designer of the tool, however, are the deciding factors in this.

It is apparent that considerable strain is thrown on the texture of the metal in blanking; the result

of this is that a slight burr or rough edge is made on the stock being blanked. This edge tends to adhere to the sides of the punch when it ascends to the up position. Consequently some provision must be made to prevent this, which is the function of the stripper. It consists of a plate which is attached to the die, having an opening for the punch to pass through, and a gap between its face and the face of the die, wide and deep enough to pass the stock freely. This form of stripper is shown in fig. 15. Other forms of strippers are cam actuated, and one type is attached to the punch. The latter form consists of a plate suspended from the punch by means of loose bolts. These bolts are sometimes known as "dancing" bolts, the distance between the inner face of the die and adaptor being kept by means of rubber blocks. These blocks being compressed when the machine is in action, allow the punch to enter the die to the depth required, and regain their former position when the stroke of the machine reverses, thereby forcing the stock off the punch.

Great care should be taken in setting a punch and die to ensure that they are set absolutely in line with each other, the slightest deviation from it being sufficient for both die and punch to become seriously damaged the moment the clutch is engaged and the ram, carrying the punch, descends.

Press tools are also used in connection with the stripping away of the surplus metal, commonly

known as the "fin" of a stamping made in a drop-hammer die. The method of construction is practically the same as for the punch and die already described, with the exception that a stripper plate is not required.

The construction of press tools, it must be borne in mind, is largely a question of the capabilities and initiative of the person making them, each particular blanking being a problem in itself.

The foregoing, however, will be found to be more or less the lines and principles upon which they are constructed. The following are a few practical points which may often have to be dealt with. Small punches which have annular marks left on them from milling or filing are much more liable to fracture than those without them, especially when punching heavy stock. This is due to the fact that the metal presses into the lines or marks, thus increasing the force required for stripping. To this may be attributed the well-known fact that more punches break while stripping than while punching. The stripping is therefore of the utmost importance, and should be made as easy as possible.

When a die has a number of punches of various sizes on it, it is as well to make the large ones slightly longer than the small ones, as the jar which takes place when the stock is entered tends to shift it slightly. Should a smaller punch enter the metal at the same time, this will be sufficient to break it.

This practice of varying the length of the punches has the additional advantage of distributing the weight required to punch the holes, thereby making it possible to use a size of press which otherwise would have lacked the capacity for the work in hand.

When a die becomes so worn that the opening is too large or "bell mouthed," it can be "reworked" by first of all heating it to a temperature suitable for forging. It is then "set in" with a suitably shaped punch and hammered until the hole is reduced below its original size. After being annealed or softened by heating to a dull red, it can be reworked to size. This procedure is highly desirable, as it gives a tool quite as good as a new one, and thus obviously saves a great deal of expense.

The dies of press tools are often made on the sectional principle. This idea is generally adopted for large work in order to facilitate manufacture, and also on account of the fact that the danger of the die warping when being hardened is reduced to a minimum.

The sectional principle is also often adopted where a particular portion of the die is subjected to severe strain, it being possible thereby to replace this portion easily should it become damaged or worn long before the remainder of the die shows such signs.

A spar box as shown in fig. 11 would be a suitable one for the adoption of a split or sectional die.

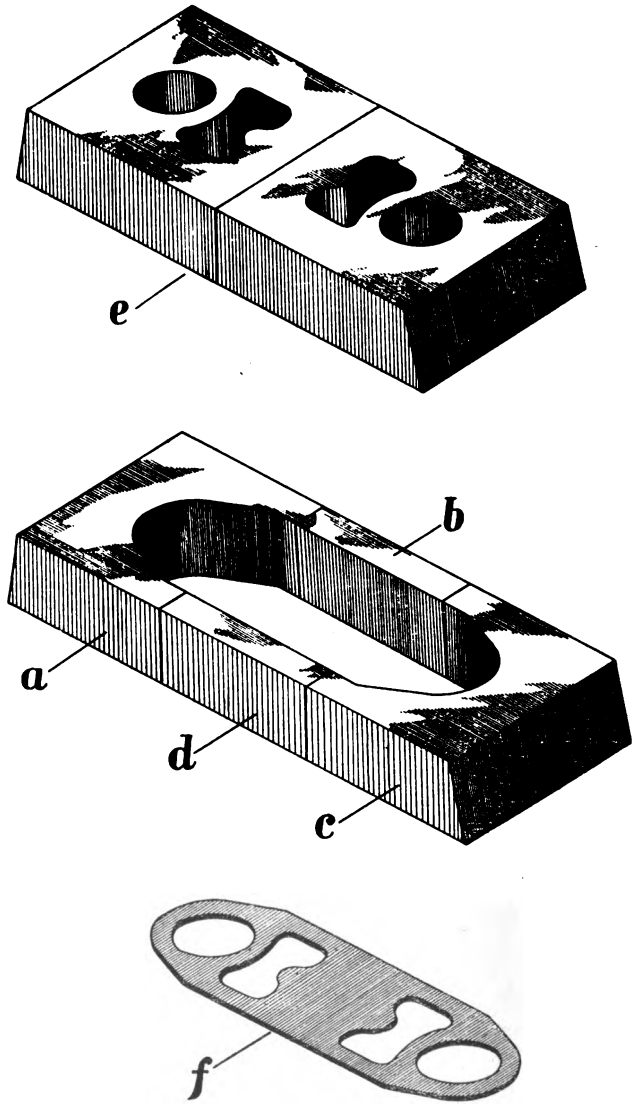


FIG. 23.—Sectional dies for spar-box blank.

The construction of it is shown in fig. 23. The diagram shows the two dies which would be used for producing the blank and piercing the holes in the spar-box plate (*f*). The upper die is simply made in two halves (*e*), while the lower one is built up from four distinct pieces (*a*, *b*, *c*, and *d*). In

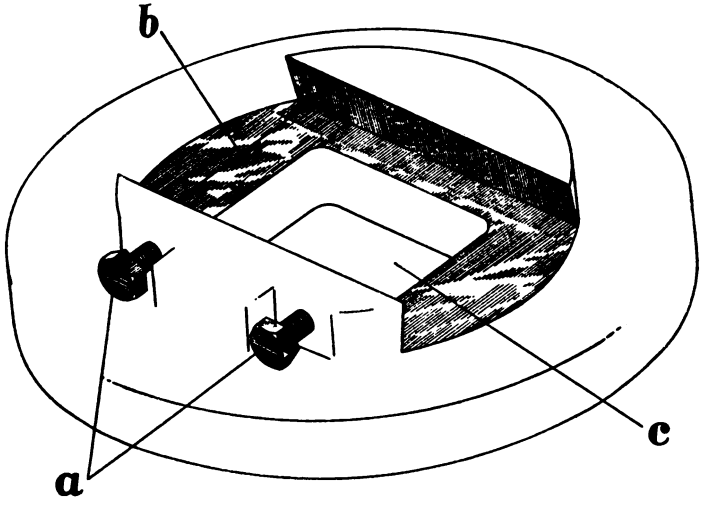


FIG. 24.—Bolster.

this latter case special precautions must be taken in order to ensure the parts shall assemble properly, with all edges in perfect alignment and all tapers matching. However, careful and accurate workmanship to fine limits are necessarily the accomplishment of every tool-maker, so that no difficulties should occur in this respect. The methods adopted for its construction and use are substantially the same as for the die already described.

Dies of all types are usually held in position on the bed of the press by means of a holder commonly known as a bolster. This is generally made of cast iron, and with substantial proportions. It is an item upon which the life of a die often depends, as, should the bolster have the slightest chance to move under the strains imposed when blanking or stripping, the result is usually a crashed die and sometimes a broken press. The importance of the bolster, therefore, cannot be overestimated. A very common type is shown in fig. 24. The slot (*b*) for the die on this type of bolster is usually machined out to the same angle as the sides of the die, and a slot (*c*) provided to enable the blanks to drop through. The die is clamped in position by the set screws (*a*) after it has been carefully lined up with the punch.

CHAPTER III

CONSTRUCTION OF TANKS

TANKS for petrol, oil, and water as used on aircraft are designed with the following principles in view: minimum weight, maximum strength and capacity, while taking up a minimum amount of space in the aeroplane for which they are intended. It therefore follows that if the maximum strength is to be obtained the workmanship must be of the highest order, as the design has been cut down to the lowest possible limit in order to attain the requirements of the minimum weight.

The tank as shown in fig. 25 is taken as being a good example of the modern type, and it is proposed to give a short description of the method of constructing the tank, and to follow this by a detailed description of the more important processes involved therein. This particular tank has a capacity of 100 gallons of petrol, and is made up of the following parts, as illustrated in the figures:—

(*a*) *Shell*, which forms the main part of the tank.

(*b*) *End plates*, which complete the structure.

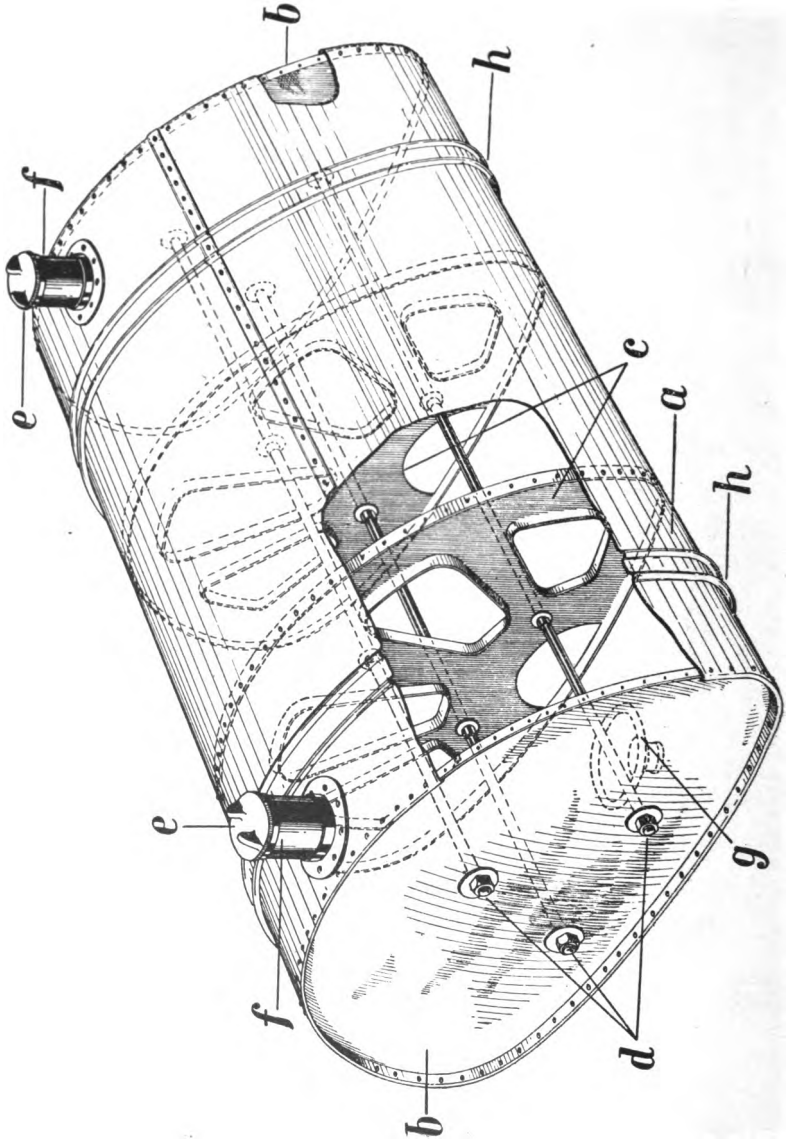


FIG. 25.—Tank.

(*c*) *Baffle plates*, which are intended primarily to stop the petrol from surging from one end of the tank to the other during a sudden change in direction of the motion of the aeroplane. Incidentally, they also form additional stays to prevent the tank from collapsing under side-pressure.

(*d*) *Tie-rods*; these are connected to the baffles and the end plates, their function being to stiffen up the tank generally.

(*e*) *Filler caps.*

(*f*) *Necks*, through which the petrol is poured.

(*g*) *Sumps*, which are usually provided in order that the last possible drain of petrol may be taken from the tank.

The shell (*a*) is made up if possible from a single sheet of tinned steel bent to the required shape. It is important to avoid making up this piece out of several small sheets, necessitating the making of several seams, which all give extra likelihood of having leaky joints. In choosing sheet for this work, particular attention should be paid to the surface, as irregularities of this are the only possible clues to bad formations in the metal. Defects such as blisters, laminations, etc., can usually be seen wherever the coating of tin appears to have been interrupted in its flow.

Another important point to look for is that the sheets shall be of uniform thickness. This, however, should be guaranteed by the sheet metal stores,

who will presumably have tested these for inaccuracies when they were delivered.

The first operation in the construction of the tank is to mark out the development of the shell on the flat sheet, giving the exact dimensions in the flat, and allowing sufficient for whatever seams will be required at the various edges. All openings for fillers, sumps, etc., should be marked out while the sheet is in the flat state, as it is much more difficult to set out dimensions accurately on a curved surface.

The question of marking out the rivet holes at this stage is a debatable one, some makers preferring to do all the drilling before the metal is bent, so that it can be done on an ordinary drilling machine without special appliances, while others prefer to drill these holes after the tank has been formed and the joints roughly soldered. This latter method is probably the best, as there is then no question as to whether the holes in the two plates will actually match when bent into position; but it does not lend itself to rapid production of quantities, and also calls for special arrangements for supporting the inside surface of the tank while the hole is being drilled. The sheet is now cut along the outside lines with a pair of shears, and the larger holes for the neck and the sump cut where required.

The shell is now ready for forming, and this operation again depends entirely upon whether a few experimental tanks are being made, or a larger

quantity for production work. Referring to fig. 26, the method is shown here to make up a tank when only a small number are required. Two templates (*c*) are made to the drawing, showing the outline of the tank, and also a number of small templates for the curvature (*b*) are used. The sheet is bent round the lower part of (*c*) after having had the grooves for the joint, as shown at (*a*), rolled in it. The small templates (*b*) are then soldered at intervals along the bottom edge, so that it can be ensured that the correct curvature will be obtained all along the tank.

The rest of the sheet is then bent over to conform to the top edge of (*c*), and the joint itself lapped over, as shown at (*d*). The end templates (*c*) are then knocked out and the tank slid along a steel mandrel (*f*), which is supported at a convenient height upon two bearers on the bench. The joint is then folded down so that the main plates forming the tank are on the same level (see (*g*)), by means of a hand grooving tool (*e*). This tool is held in position at one end of (*c*), and is then lightly hammered, gradually being moved along the joint at the same time. In the case of production of larger quantities, instead of using separate templates (*b*) and (*c*), a large former of the correct outline of the tank, but somewhat longer, with suitable supports at each end, would be made up either in hardwood or metal and the steel plate bent round it until it conforms to its outline. This is obviously

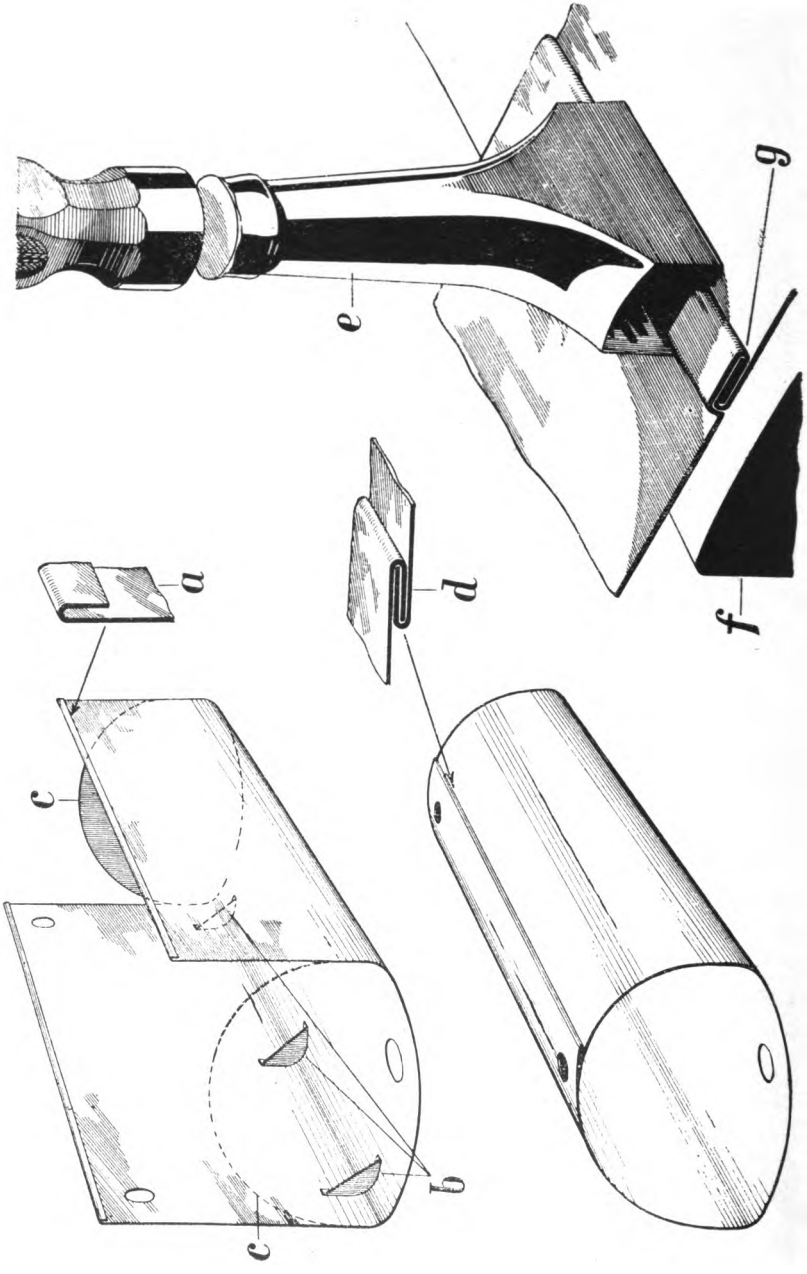


FIG. 26.—Construction of tank shell.

a much quicker process, but it is not worth while going to the extra expense of manufacturing this former unless there are a fairly large number of tanks to be made.

The bending of the shell, or "forming," as it is usually called, must not be done before the metal has first of all been well stretched or "broken down." This process is carried out by placing it between a set of three steel rollers, which are revolved after being adjusted to a certain tension, depending upon the thickness of metal used and the size of the radius to which it is to be bent.

The sheet is passed through these rollers, and emerges curved, the radius of the curve being more or less determined by the pressure on the rollers. It is then passed through the rollers again with the curve reversed. Finally, the tension between the rollers is so adjusted that when the sheet passes through them it emerges flat, and the metal stretched in this manner is easier to manipulate.

The type of joint shown in fig. 26, which is known as a double-flanged joint, is the one which has been most favoured during the late war for petrol tanks; but it is now becoming questionable as to whether the simpler ordinary lap joint is not superior, as it is easier to get a film of solder through this, and it is really this covering of solder that ensures the tightness of the joint. If it is possible to make a satisfactory joint of this description its advantages are obvious, from the point of view of cost of

production, as the first operation of grooving the plate is entirely done away with.

The joint is now clamped by one or two small bolts through the rivet holes, in order to prevent it coming apart during the process of riveting. The rivets are then placed in position from the inside of the shell and the head carefully formed on the outside. Careful riveting is of the utmost importance, as "spread" holes and unevenly "snapped" rivets are the cause of more leaky joints than anything else. One of the general causes of unsatisfactory riveting is the failure to support the head of the rivet inside the tank properly while the outside head is being formed. They should be held by a steel arm with a cup in the end, of exactly the same shape as the rivet head, and care should be taken to see that the head is actually in the cup before commencing to hammer down the end of the rivet. Some suitable means of support for this arm should also be devised, as if it is merely held sideways in a vice it gradually drops and its upward pressure is no longer exerted properly on the head of the rivet. After this outside head has been hammered over roughly by hand with a small ball-paned hammer, it is finished off with a hardened steel snap with a hemispherical cavity in the end corresponding to the standard size of the rivet head for the particular size of rivet being used.

The next process will be that of soldering the seam, which is necessary not only to secure it but

also to protect the raw edges of the metal from rust. A full description of soldering is reserved for the latter part of the chapter which describes the various processes more fully.

It is advisable at this stage to stiffen the shell by the addition of several small beads which can be placed wherever convenient, or, as is often the case, placed in pairs as shown in (*h*) fig. 25, in order to form a guide for preventing the securing straps from slipping along the tank. Some makers also prefer to put a bead just behind the joint between the shell and the ends. This has the advantage of serving as a guide for the placing of the end and so stops blobs of solder from running down into the tank when this joint is being made. The actual size of these beads would naturally depend upon the size of the tank, and in the case of the tank in question they were actually $\frac{3}{16}$-in. radius. They are made by passing the metal between a pair of rollers carrying a projection on one and corresponding channel on the other, fixed in either a hand or power rolling machine. The amount of clearance between these two rollers must be very carefully adjusted by hand on the screw provided, in order to suit the particular metal in use. If the metal is stretched beyond its limit, it will be permanently weakened even if cracks are not developed at once, and will certainly collapse sooner or later. This process is fully shown on fig. 27, which should be quite self-explanatory.

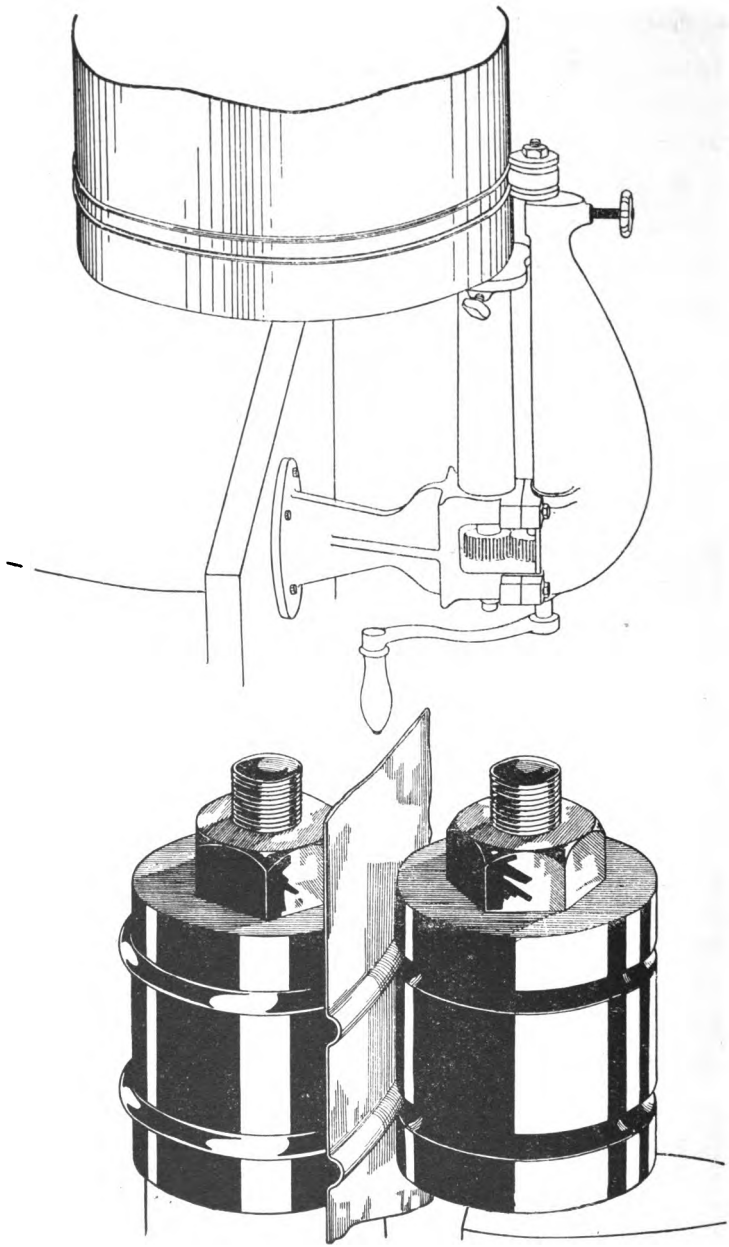


FIG. 27.—Beading.

The next item to be dealt with is the end. This is probably made of the same thickness of metal as the shell, and its construction is somewhat the same. First of all, the piece will be marked out in the "flat" to the correct dimensions, allowing sufficient for the seams. Here again the processes are different for quantity production from those used for the making of a few tanks. When only a few

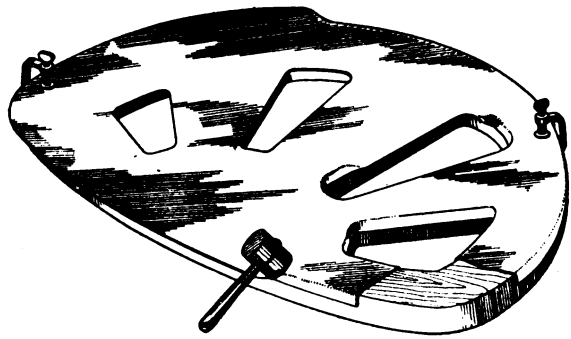


FIG. 28.—Construction of baffle.

are required, it is usual to make a wooden former of the necessary shape, and if holes corresponding with those in the baffles are also cut in this former it can be used for the making of these as well. The sheet, having been cut to shape, is held on to the forming jig with clamps and the edge turned over by hammering, as shown in fig. 28. If it is a baffle under construction, the holes are also hammered over in the same manner.

This process would complete a baffle, but if it is an end under construction it usually has to be bulged

as well. This is done by placing the same between a pair of planishing hammers which gradually stretch the metal to the required shape. This process is one which requires a certain amount of skill in order to avoid cracking the metal. First of all, the hammers should be applied as near the centre of the end as possible, and they are then worked around in a circular path, gradually getting farther from the centre. Also great care should be taken that the hammers do not continually beat on the same place but work gradually along with a sliding motion, thereby causing the metal to slowly flow, and not to be bent sharply. This process, of course, means that there will be a very slight local decrease in the thickness of the plate, but if properly carried out it is not appreciable.

If a number of tanks are to be constructed, these ends and baffles should be made as pressings. This is a much quicker and more satisfactory process, particularly as it does not call for the highest type of skilled labour, and there are not the possibilities of damaging the texture of the metal. During the war a period of great development in the use of press tools on this class of work took place. A fuller description of these will, however, be more in place in the chapter on the use of press tools in general.

The baffles should be made of material slightly stouter than the shell and the ends, owing to their having, under certain circumstances, to break the

actual load of the contents of the tank without having the natural bracing which the other parts of the tank possess.

The next item which is called for in the making of a tank will be the tie-rods which pass from one end of the tank to the other, supporting the ends and baffles in their respective places. These rods will have been made previously in a machine shop from a good-quality mild steel bar screwed at each end to take the size of nut required (in this case a $\frac{1}{4}$-in. diameter), and tinned all over to prevent rusting. At the point where they pass through the baffles, a special socket will have been previously fixed in position in order to form an extra bearing surface. It is usual to fix the tie-rods to this socket by soldering as well, in order to lend additional stiffness to the baffles. These rods are afterwards secured to the two ends by nuts with washers both inside and outside the tank, the whole being made petrol-tight by carefully soldering over. The method of fixing these tie-rods is fully shown in fig. 29. In the type of tank under discussion there should be at least two of these rods, the number being naturally determined by the designer when making the drawings. The stiffness required in a tank depends partly upon the load of petrol carried, and also in some cases upon the fact that the tank is used for other purposes, such as to form part of the seating.

Filler caps and their seatings, shown in fig. 30,

are usually made of cast brass with leather washers inserted to provide the necessary joint. The cap should always be attached to any convenient part of the tank by a small piece of chain or a lanyard, in order to prevent it being laid aside and lost while the tank is being filled. It is also a good

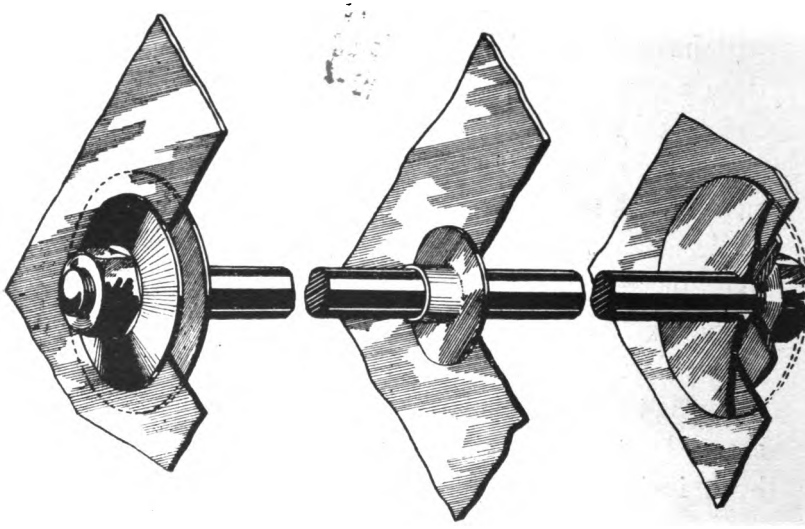


FIG. 29.—Tank stay bolt.

practice to stamp the capacity of the tank upon the filler cap. These fittings are usually tinned all over.

If the tank is fitted in such a position that the filling of it is difficult, it is advisable to provide the filler with an extension, as shown in fig. 30; otherwise the petrol is apt to be splashed inside the fuselage, which is not only wasteful but dangerous, from the point of view that the fuselage in the vicinity of the filler is more liable to catch fire if

thoroughly soaked with petrol. This can be most conveniently made from a piece of steel tube of the required size tinned all over as usual.

The sump is one of the most important details in the tank, as it not only forms a natural trap for all heavy foreign matter which may have got inside

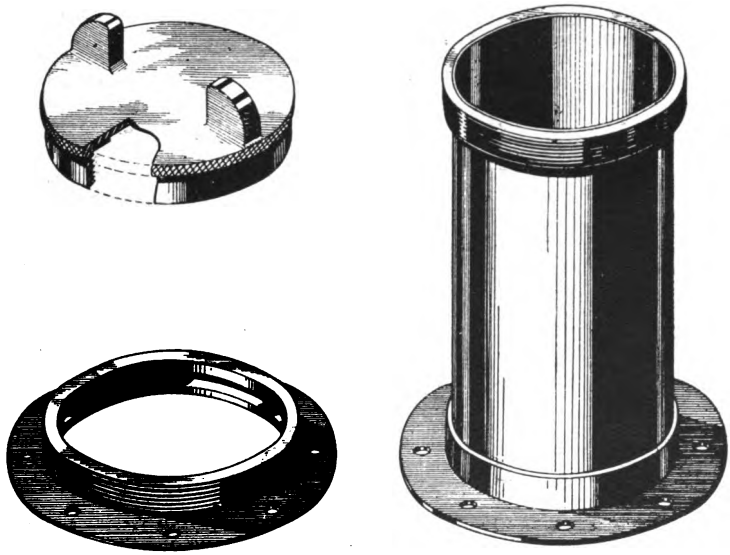


FIG. 30.—Filler cap, seating, and extension.

the tank through various reasons, but enables every drop of petrol to be utilised if necessary. If a sump is not fitted, small pools of petrol will collect in any unevennesses in the base of the tank, which is inevitable in all tanks made of sheet steel. The sump itself is made up either from sheet steel cut out and bent and welded up, or else "spun" to the shape required. The "spun" or pressed sump is

preferred in every way. The usual method of spinning is to make two wooden blocks of the required shape of male and female form respectively. These are fixed in a lathe and the plate placed between them. The female block is then revolved, and the male block gradually forced into its position, thereby stretching the metal to the shape required, as shown in fig. 31. The brass fitting for a drain cock or pipe connection is then riveted in position and soldered up, and the hole through it is drilled

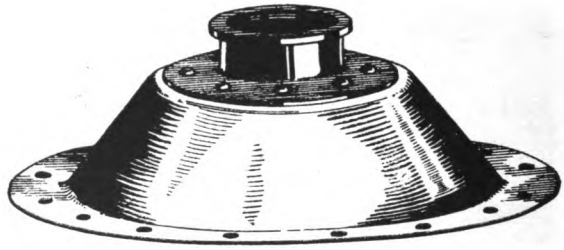


FIG. 31.—Tank sump.

through the base of the sump. Some makers prefer to introduce a piece of fine gauze in the sump here, in order to prevent the passage of foreign matter through the pipes. As it is difficult to remove this for cleaning purposes after the tank is once made, this practice is not recommended. A much better way of overcoming this trouble is to introduce a filter which can be easily removed for cleaning purposes at some other point of the petrol piping.

All the details which are necessary for the making up of an average tank have now been dealt with,

and it will now be convenient to discuss the various processes in assembling them to form the complete article.

The baffles are first slid along the shell into position and the rivet holes in their flanges drilled. The holes of the shell having already been drilled, they can be continued through the flange of the baffle at once by means of a portable drill. The rivets may now be placed in position with the aid of a supporting bar inside and "snapped" on the outside, care being taken that the baffles are fixed squarely with the centre line of the shell during this operation. The next thing to be done is the soldering of the baffle to attach it to the shell. This must be carefully carried out, as, should the solder not flow evenly, small beads will form, and when the tank is in use these become detached owing to vibration, and are carried down to the petrol piping, causing damage to the many delicate pieces of mechanism through which they will have to pass.

The tie-rods should now be assembled, the supports for which have already been fixed to the baffles. The rods are threaded through these and soldered in position. The filler cap seatings, sumps, and any other fittings which are called for, may now be fixed by placing them in position and drilling the holes, riveting, and soldering. The first end can be now placed in position and fixed by means of the tie-rods, which pass through holes

provided for them. The holes in the flange of the end are next drilled through the holes already drilled in the shell, and the rivets inserted and snapped on the outside, as already described. These should be spaced evenly around the periphery of the tank; their pitch, of course, will be settled by the drawing.

The next operation will be the soldering of this joint. The actual method of carrying this out depends upon the plant available. Electrical heated "bits" have proved their value, but as they are hardly in common use yet, it would probably be better to consider the ordinary "bit" heated in a bench gas stove to the required heat, which should be just hot enough to make the solder run evenly. When this temperature is reached it should first of all be dipped in "killed spirits" in order to provide the necessary flux to enable the solder to run freely through the joint, the faces of which have been lightly brushed with the spirits previous to the assembly. The actual operation of soldering is quite simple, the "bit" being taken in one hand and a small piece of solder in the other; these are rapidly passed along the joint once or twice with the solder actually in contact, care being taken that no portion of the joint is missed. It is extremely important that this operation should be carried out both carefully and thoroughly, and it should be remembered that good soldering can only be obtained on a really clean surface. It often happens

that when a batch of tanks are in construction and the detail parts are prepared in batches, the raw cut edges of the metal which are not protected by the tin have to be left exposed for some considerable time. The atmosphere of a tank shop is permeated with the fumes of the "killed spirits," and this in due course produces a heavy coat of rust on the exposed edge. It is consequently important to ensure that if the delay between cutting the plate and finally soldering up the joint is inevitable, all such edges as this must be carefully cleaned before commencing operation. The end plate having now been soldered in position, the joint is completed by turning the portion of the shell allowed over the edge of the end. A tank, before this turning-over operation takes place, is shown in fig. 32, the enlarged view at (*a*) showing the joint after soldering with an extra lap remaining on the shell. The view (*b*) shows this lap turned back into its final position. Simple turning-over tools are easily made, and must suit the particular shape of end and joint required. This operation should be carried out by placing a support inside the edge of the end and hammering from the outside. The joints should then be heavily loaded with solder, care being taken that no beads form on the inside edge, and then thoroughly cleaned off with a piece of cotton-waste. It might be well to again emphasize here that heavily soldering the joint does not mean simply plastering the joint with an uneven

mass of solder, but the aim should be to get an evenly spread film over the whole of the surface.

The nuts on the tie-rods outside the tank can

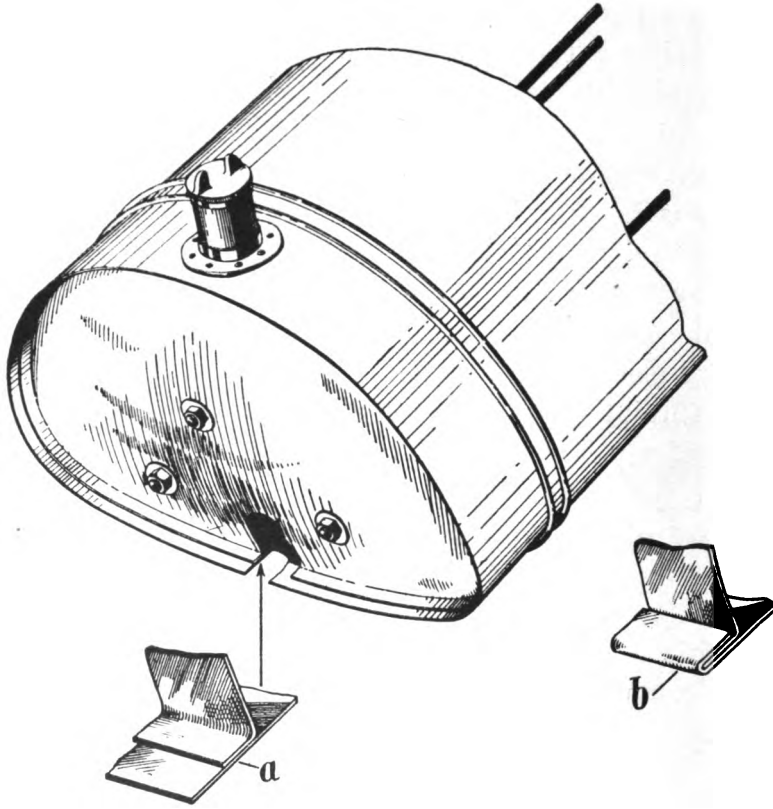


FIG. 32.—Tank before bending over ends.

now be permanently fixed, and this is best done while the solder is alive, having secured the necessary film of solder under the nut before it is tightened down. Before fixing the remaining end it will be wise to subject the tank to a rigid in-

spection, to ensure that none of the faults already pointed out have occurred during its construction. This is of the utmost importance, as it is obvious that considerably more trouble and expense will be entailed in getting such faults put right after the other end is in position and the inside cannot be reached. With regard to the fixing of the ends, it is sometimes found that through an error in the size of an end plate there is too much clearance between the flange and the shell. Under these circumstances this space should be packed with thin strip metal before riveting, and it should never be left to the rivets alone to take up this inaccuracy. The final operation of fixing the remaining end will then complete the tank. It will be wise, as an additional precaution, to go over all of the external fittings, examining particularly all rivet heads to see whether there are any breaks in the film of solder, which may result in leaks.

The tank is now complete and ready for a leakage test. All the seams should be coated with a thin white paint, and all outlets closed. Air is then pumped in to a sufficient pressure, usually taken at about $2\frac{1}{2}$ lbs. per sq. in., and the tank is then placed under water and left for at least an hour. Should there be any faults in the joints, the leaks will be easily traced from the bubbles which will be made in the water by the escaping air. This test should be carried out rigorously, and any part of the tank which shows signs of a likelihood of giving way

should never on any account be passed over. It is often the case in dealing with aeroplane design that tanks utilise portions of a body or wings of a machine in order to economise space, and if once they are placed in position and then leaks develop, it becomes not only a question of repairing the tank, but also of partially stripping the machine, in order to get at it.

The tank should now be finally examined so as to see that the vent holes, if called for, are clean, and some suitable covering provided for end openings, which have to be left in order to prevent the entry of any foreign matter until it is finally connected up with its piping.

Processes of Manufacture.

The use of "killed spirit" as a flux should be carefully watched, as, should any appreciable amount of this remain in the joint, corrosion will occur. This mixture is commonly called "killed spirit"; it is usually a solution of zinc chloride. The preparing of this is well worth consideration, as, although it is in common daily use in the workshop, there are often other acids of similar appearance but different action also in use, and there is a danger of their being interchanged.

The solution is composed of zinc and pure hydrochloric or muriatic acid, not "spirits of salt," which are an ironmonger's inferior substitute. To mix to the best advantage, take a stone vessel of the size

required and fill with the acid; then stand in the open. This is necessary on account of the action of the spirits on any steel or iron objects in the immediate vicinity.

The zinc should be applied in the form of finely snipped new sheet zinc, and when the disturbance occasioned by dropping the first piece in has moderated, put in the rest. Be sure to provide an excess of zinc, that is to say, observe that a quantity of same remains undissolved at the bottom of the jar after all chemical action has ceased: hence the name "killed spirits." Let the solution stand for at least twelve hours, then decant into a suitable jar. Do not add water to the concentrated zinc chloride; this is often recommended, but should never be done. The alleged cleaning qualities of this flux can scarcely be admitted to exist, its principal function being to shield the surface of the metal to be soldered from oxidation.

This it fulfils by the formation of a glaze on the heated metal, when the salt in the spirits reaches its waterless condition by evaporation. The water, therefore, only prolongs the period occupied by evaporation, and wastes time. Always remove all traces of this flux from the finished work, first by wiping with a wet rag, then by soaking and washing in soda water, otherwise corrosion will certainly occur.

Applying the Flux.—A short heavy glass jar is the best for bench use as a flux container. It should

be particularly noted that the container should be kept as far away from other metal work as possible. A pointed wooden stick is not a good tool for applying "killed spirit," because the acid acts on the wood and it becomes unpleasant to handle; also the liquid does not readily leave wood, thereby preventing one from placing the right quantity on the exact spot to be soldered. A coarse hand brush fixed in a metal tube is the best for all purposes.

It is desirable to remember that this flux is poisonous, also is liable to produce subsequent rusting wherever used, unless thoroughly removed after soldering; it is therefore unsuitable for soldering food retainers. A good non-poisonous flux suitable for vessels intended for food may be made by dissolving resin in oil, colza or olive.

Soldering.—Cleanliness in everything connected with the process of soldering is essential to success. The ordinary procedure in making a joint is to clean the surfaces first by filing or scraping, or by the use of diluted hydrochloric acid. In the case of tinned steel this is not necessary.

With or without preliminary heating of the work, flux must be applied to the joint, and with the heated bit held in one hand, the stick of solder in the other in contact with the same, the whole should be passed lightly along the joint. This will cause a line of molten solder to run, and some skill and care are necessary to get just the right amount of solder without waste, and not allowing it to spread

in a lumpy fashion beyond the joint. The bit is next worked up and down the joint to spread the solder, and by the transmitted heat to make it thoroughly penetrate the joint. Some beginners at soldering try to solder "uphill," that is, they hold and place the work in such a way as to cause the solder to flow away where it is required.

The correct method is to solder "downhill" by tilting or inclining the work, so that the solder will always collect around, and travel with, the point of the bit.

Tools used in Tank-making.

Copper Bits.—The soldering bit or bolt (miscalled an "iron") carries a pointed lump of copper at the

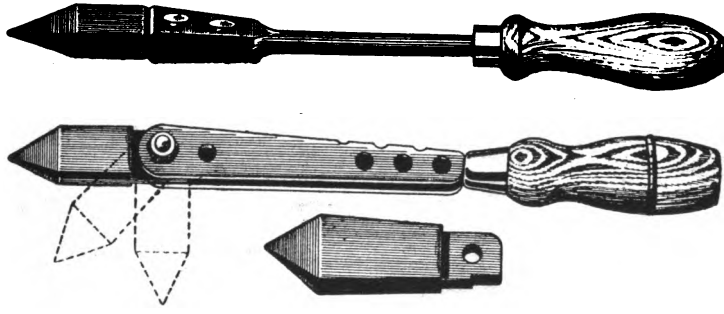


FIG. 33.—Soldering bit and pivoted soldering bit.

end (fig. 33), riveted in or otherwise fixed to suit the particular type of work in hand. Some bits are pivoted to enable them to point at various angles for dealing with difficult situations. The size of the bit required varies according to the size of the work. For ordinary use the actual weight

of the copper should be approximately 1 lb., and before it can be used it must be tinned, that is, completely covered with solder. This coating must be renewed as required.

Stoves for Heating Soldering Bits.

Fig. 34 gives an impression of the type of gas stove most commonly used, although a copper bit

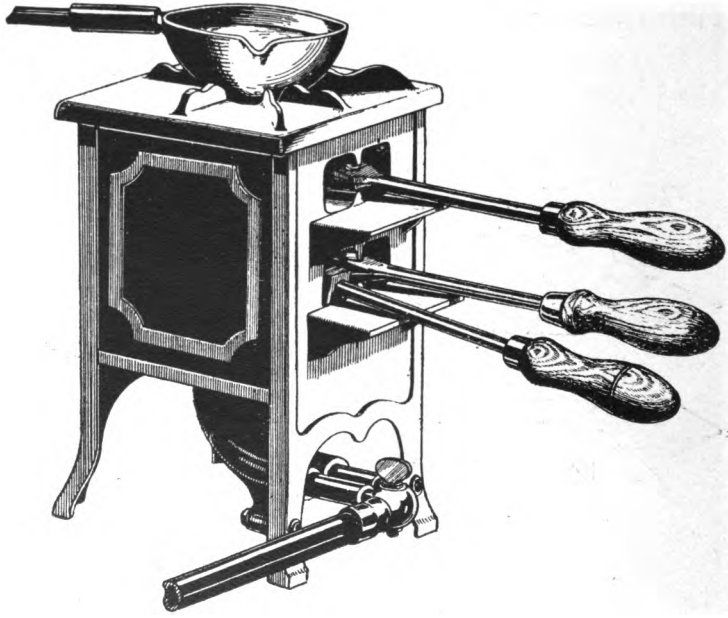


FIG. 34.—Gas stove for heating soldering bits.

may be heated in any fire. It is advisable to avoid the dirt, smoke, and tarry stickiness associated with a coal fire. In the absence of gas, a bright, clear coke fire or a charcoal fire should be used whenever available. Portable oil stoves of the wickless type

can also be employed, but the ideal fuel is gas, which may be regulated at will to give a uniform temperature. It is advisable to heat two bits, one heating while the other is in use.

Solder Ladle.

The ladle shown in fig. 35 can be used for making the strips of solder commonly used in tank-making

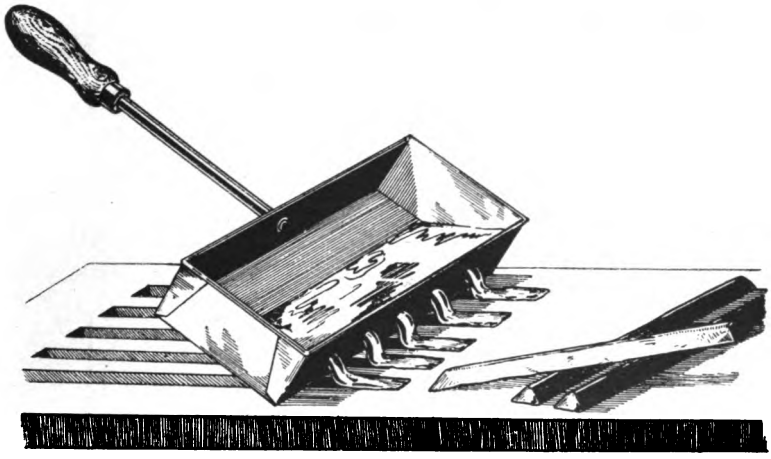


FIG. 35.—Solder ladle.

this is done by filling the receptacle with the molten mixture of tin and lead, then allowing the same to run out of the holes provided, on to a clean board, drawing the ladle along the board as the strip forms, the length of which depends on the amount of solder which the receptacle is capable of holding.

Material used in Tank-making.

Tanks are usually made from the following materials—tinned sheet steel and copper sheet;

the rivets are of copper or steel, and the various fittings of either steel tinned over, or brass.

The best solder used consists of 50 per cent. tin and 50 per cent. lead. A solder should melt at a slightly lower temperature than the metals which it unites, and should possess the quality of alloying with the two surfaces, thus making a true metallic joint.

CHAPTER IV

GENERAL SAWMILL WORK

THE object of this part of the work is to present a *résumé* of the ordinary everyday knowledge which would be required in a sawmill attached to an aeroplane factory. It does not aim at giving an exhaustive botanical explanation of the various woods used. This function is fulfilled by several excellent books upon this subject, to which the reader who desires to specialise in this branch of the work is advised to refer for fuller information.

Trees for timber are known botanically as exogens, or outward growers; that is, the new wood is added periodically to the outside of the tree directly under the bark. New wood is formed by moisture taken up by the roots from the soil. This moisture is converted into sap which passes up between the last-formed wood and the bark, in the spring, causing the leaves to form. It then remains stagnant during the summer, taking up carbonic acid gas, which causes the sap to thicken. In the autumn it returns to the roots, leaving a residue behind which composes the new wood.

Fig. 36 shows the transverse section of a tree.

(*a*) shows the pith or medulla, a soft spongy substance which generally dies right out as the tree matures.

(*b*) is the heartwood, or duramen, the part of the tree used for all good constructional work.

(*c*) are the medullary rays, vertical layers radiating from the pith to the bark, which convey a portion of the descending sap to the vessels in the interior of the tree to complete the formation of the various tissues.

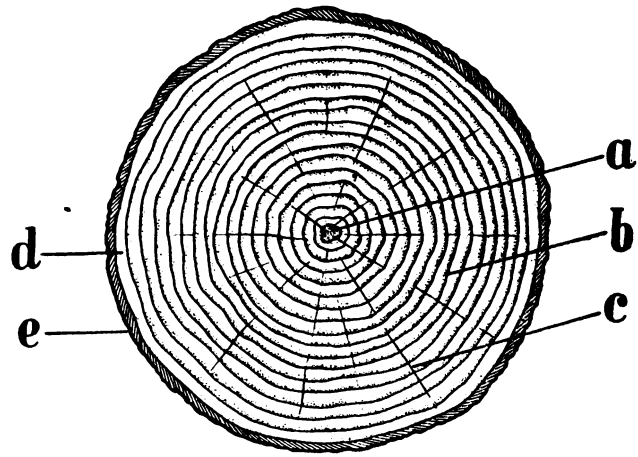


FIG. 36.—Nomenclature of timber.

(*d*) shows the sapwood or alburnum, the immature wood on the outside of the tree.

(*e*) shows the bark, the protecting coat of the tree. The whole is built up of concentric

layers known as annual rings, a new ring being added each year. These are formed of cellular tissue and woody fibre. When the moisture is drawn up in the spring, the bark becomes loose and a fluid called cambium is secreted between the bark and the last-formed wood. This is converted into the cellular tissue of the next annual ring, and is known as the spring layer. In the autumn the woody fibre commences to grow from the upper part downward. This forms the dark-coloured ring in each annual layer. The fibres obtain their nutriment from the cambium and become attached to it, forming the autumn wood. As the sap descends through the outer layers it is carried to the interior of the tree by the medullary rays gradually filling up the first-formed annual rings with substance which solidifies, forming the heartwood.

Timber should be felled in mid-winter when the sap is at its minimum and its growth stagnant.

After felling, the logs should be removed from the forest immediately and not allowed to remain on the damp ground for an indefinite period, otherwise the timber will deteriorate. The logs should be taken to the sawmills and properly stowed until required for cutting, care being taken to keep them straight and to allow the air to circulate freely all round them.

A good foundation should be made so that there can be no vegetation under the logs.

Fig. 37 shows a number of logs stacked properly. (*a*) are timbers known as dunnage, which are laid crossways to take the bottom layer of logs. Old railway sleepers are very useful for this purpose. These should be laid from three to four feet apart,

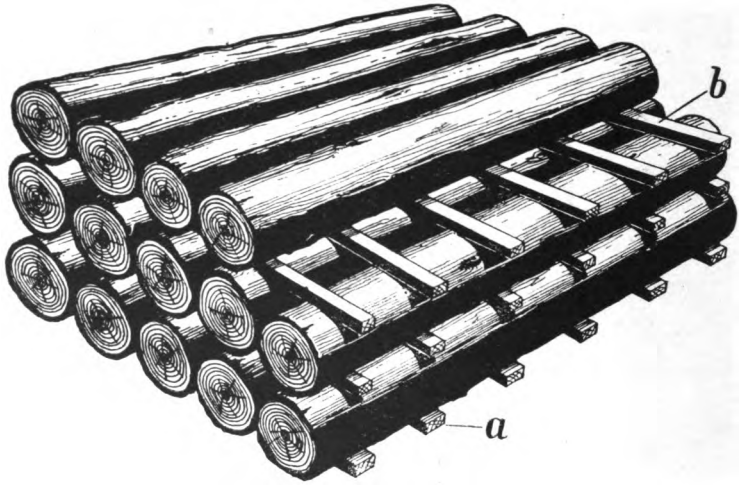


FIG. 37.—Stacking of logs

care being taken to keep their top sides level and out of twist. The first layer of logs is laid on the dunnage. After this, some quartering, known as skids (*b*), are laid on the logs, these skids being blocked up where the logs are of unequal thickness. They are laid between each layer of logs as the pile goes up. Every skid should be exactly over the underneath ones and the dunnage, or the weight of the top logs, will cause the bottom logs to bend

and become set in this shape. This will reduce their value considerably from the point of view of producing long, straight planks.

Care must be taken not to damage the bark, as this will protect the timber from the weather. The open ends should be protected with a covering of cow dung and clay or one of the commercial compounds now upon the market.

The woods to be dealt with in this work can be grouped under two distinct heads, *i.e.* hard wood and soft wood. The former include ash and hickory, and the latter spruce almost entirely. There are a few other soft woods, which may be used as a substitute for spruce, but none of them combines all the qualities of this wood. If the works includes the manufacture of air screws, mahogany and walnut will also be added to the list of hard woods dealt with.

English ash (Fraxinus excelsior) is the best wood for aircraft parts subjected to heavy shocks.

It is grown in most parts of this country, but all ash is not suitable. It must therefore be carefully selected. The trees most suitable are those grown in a coppice, where they have grown up in close formation, generally with other trees. This will produce trees giving good lengths of straight timber. Those most suitable are from eighty to a hundred years old. Trees from the hedgerows will also give good timber if the soil is good, but are generally shorter than those in a coppice, although where not

over-matured they are somewhat tougher. Very large trees should not be used, as they will probably be over-matured and have lost their elasticity. When selecting ash it should be seen that it is of good average formation, clean of growth, straight, and free from objectionable irregularities. The bark should be clean and smooth, and should show signs of quick growth.

The defects to be avoided in ash can be roughly grouped as follows:—

Timber past Maturity.—It will be seen that the pores are empty and void of secretion, and the fibre tissue more or less brown in colour. This timber is brittle, having lost its elasticity.

Rammy grain is a defect found in good ash, which might be used on almost all work except aircraft. Its limit of elasticity is low compared with good straight-grained ash. The fault is generally found at the butt end of the tree where the grain appears to be full of small curls.

Blackheart is caused by neglect or bad pruning, making a passage for moisture to penetrate to the heart of the tree, which will eventually cause it to decay in the centre. Blackheart should not be confused with brownheart. This latter is merely a chemical effect caused by the soil upon which the tree is grown, and does not necessarily spoil the wood.

Knots.—Two kinds of knots are found in wood: one is called dead, the other live. These, if not too

prevalent, can be cut out when the timber is cut up into details. They do, however, detract from the value of the timber as they divert the straight run of the grain.

Foxiness is a yellow or red tinge, caused by incipient decay, and should be carefully looked for.

Shakes.—These can usually be avoided when marking out for cutting to details, but timber containing many shakes must not be used in aircraft. They are really splits running longitudinally with the grain, generally caused by the timber shrinking very quickly.

Cross Grain.—This can generally be avoided when cutting up the timber. This defect is, as the name implies, an irregularity in the general straightness of the grain.

Sapwood.—This is the immature wood under the bark; it is not so strong or lasting as heartwood, and can easily be detected by the thin annual rings.

In ash the colour is nearly the same as the last-formed heartwood.

Hungarian ash is sometimes used as a substitute, and is very like English ash in appearance and characteristics. It is hard and tough and of fairly quick growth.

Shagbark hickory (Carya alba or Hecoria ovata) is the variety imported into this country. Logs average 8 to 18 ft. long and 12 to 28 in. in diameter at the butt end. The wood is extremely

dense, tough, and elastic, especially wood of the second growth. The logs should be converted into planks as soon as possible after shipment, or shakes will develop. It is somewhat liable to ferment, discolour, and contract fungus, and therefore needs constant attention during the storing and seasoning period.

Sitka Spruce (Picea sitchensis).—Sitka spruce is commonly known as silver spruce, but is also known as black spruce, silk spruce, or western spruce. It is obtained from the western parts of North America, where it is widely grown from Alaska to California. It is said to be the only spruce fir of commercial importance in those parts, where it sometimes exceeds 200 ft. in height, and 12 to 60 ft. quarter girth. The wood varies a good deal in quality, some being so coarse-grained that it only contains five rings to the inch. This is too coarse for aircraft work. Six rings to the inch may be allowed; but a much finer grain than this is preferable, as fine-grained spruce is more dense and elastic. Its colour is white to cream, and varies according to its density and the amount of autumn wood in the annual rings.

Silver spruce can easily be identified when in bulk, by the long rough fibres which are fairly pronounced in some of the tough qualities.

Spruce is subject to several defects. Fractures, although they can hardly be called timber defects, should be guarded against. They are probably

caused by careless handling. These cracks are so fine that very careful inspection is needed to find them in the logs, but after the wood has been planed up it will be seen that the fibres have been completely torn apart at this point. Fractures have been known to go half way through a 1½-in. fuselage member, and stop abruptly in the centre, the sound half splitting down with the grain.

Coarse grain, or timber with wide annual rings, should not be used for aircraft. This timber is soft and weak, and liable to twist and warp.

Curly grain is a peculiar growth: the grain is short and twisted.

Twisted Fibre or *Spiral Grain.*—This defect is caused by the tree being twisted in its growth so that the planes parallel to the medullary rays, instead of running vertically, twist round the tree. If the log containing this was cleft down the centre, the faces would form a spiral. It is exceedingly difficult to detect unless the timber is planed up, and should be looked for at right angles with the annual rings. If the timber is cut radially, looking at the face tangent to the annual rings, it will be seen that there are short dark hair lines or resin ducts, which run in the direction in which the timber will split.

Knots are easily detected, and must always be cut out.

Resin pockets are cavities of various sizes containing resin: large ones can be detected by the

direction of the edges of the annual rings, also the colour near them is a shade lighter than in other parts. Resin seams are defects formed by an excessive amount of resinous secretion.

Blue stains in spruce are usually the forerunner of dote, caused by the timber having been stowed in a badly ventilated place.

Dote is a very serious defect, and attacks wide-ringed timber first. It is of a reddish-brown colour, and appears in patches. When affected, the fibres will easily break apart, under very slight pressure. In no case must timber with this defect be used.

Shakes can easily be avoided when marking out details.

The following are recognised substitutes for spruce :—

Quebec Spruce (Picea alba or Picea nigra).—This timber is grown in Canada and used chiefly for sculls and oars. It is a fine grade of timber, well-selected trees being tough and elastic.

White Sea White Deal (Picea excelsa).—This produces a fine grade of wood, but must be well selected. It comes from Europe.

West Virginian Spruce or *Red Spruce* (Pinus rubeus).—This is not so suitable as silver spruce for all parts of aircraft, but has some very good qualities.

Port Orford Cedar (Cupressus Lausoniana).—This is very good quality timber, very tough, and a useful wood for aircraft, comparing well with silver

spruce. It is of a creamy white colour, darkening on exposure to the atmosphere, and has a peculiar odour.

Fig. 38 shows a pile of planks stacked for seasoning and storing. The same care must be taken with the foundations as explained for stowing logs.

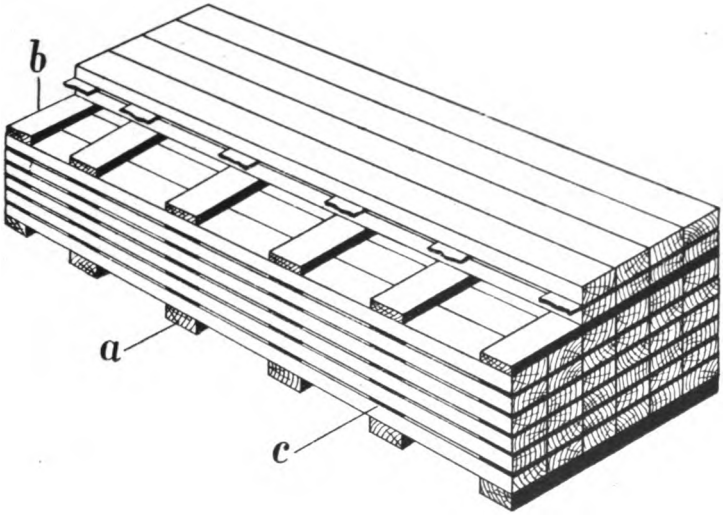


FIG. 38.—Stacking of planks.

(*a*) shows the dunnage.

(*c*) are sticks about 1 in. wide and $\frac{3}{4}$ in. thick laid between each layer of planks exactly over the dunnage; as the pile rises it is necessary to insert, at about every 4 ft., larger pieces (*b*) known as skids. These are 1 in. thick and about 3 in. wide. This will help to tie the stack together and also promote the circulation of air through it.

In no case should timber be stacked by placing one plank upon another, unless thoroughly seasoned, as this will cause the timber to ferment and ruin it. If properly stacked, as shown above, the air will circulate freely all through the stack.

Spruce, after being cut, should be allowed to remain for several days to case-harden, preferably in its own climate, before being transported. After that period has elapsed, it should be stacked under cover, wherever required, where plenty of fresh air can circulate round it.

Ash should preferably be allowed to remain outside, protected from the heat of the sun and also from strong winds and rain.

Timber commences to season as soon as it is felled, whether in logs or sawn into scantlings. Natural seasoning should always be allowed if time permits.

The timber prepared under these conditions is superior in every way. The stowing of logs and stacking of planks have been explained previously, and through all these processes timber is being seasoned. It is obvious that small planks will season more quickly than larger ones; therefore when timber is required for a job the planks should be taken into the mill, cut to the overhead sizes, and again stacked for a few weeks.

All timber will case-harden in the course of time, and will stand for any period; but if the outside crust is taken off it may go out of shape and commence to warp and twist again. If it is desired to

hasten the process of seasoning, it will be necessary to resort to "kiln" drying. This is an artificial method of seasoning timber, in which it is exposed to a moist warm air in a desiccating chamber, through which it is slowly passed. As much as is necessary of the moisture is taken out of the wood, so that there is little possibility of any shrinkage taking place afterwards.

There are several systems of kiln drying in use to-day, but there is hardly room to go into the details of it here. Even at its best it is an unreliable substitute for the natural process.

The final conditioning of timber is often a wise precaution. After the timber is sawn up, it is stacked in a well-ventilated room in a temperature not exceeding 85° Fahr. and allowed to remain until the moisture has been reduced to about 16 per cent. of its weight.

The moisture contents of timber is estimated by taking a sample and splitting it up into match sticks. These are carefully weighed and then heated in an oven until the moisture has evaporated. The dried sticks are then weighed again, and a comparison of the two weights gives the percentage of water which was contained in the original samples.

When cutting up logs into planks the term usually used in the mill is conversion. Machines used for this purpose are the log band saws, vertical and horizontal; reciprocating frame saws, vertical and horizontal. Vertical saws are considered best

for cutting planks, and horizontal saws for cutting

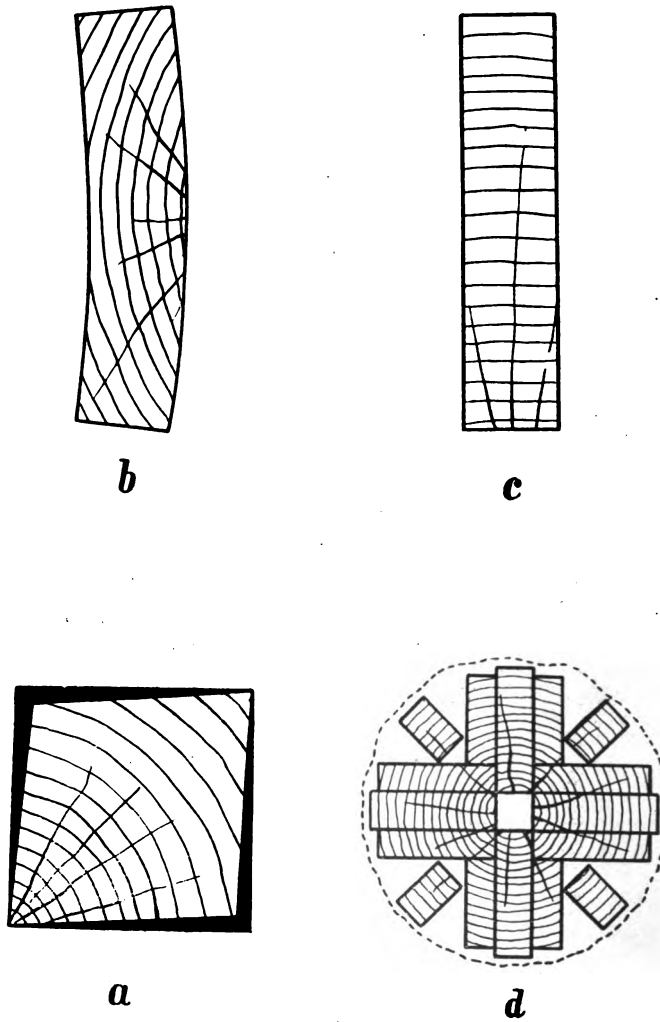


FIG. 39.—Sawing of timber.

boards. These saws are fed mechanically, the log being fixed on a moving rack or table.

When cutting up timber care should be taken to cut it to the best advantage for the particular kind of work for which it is required.

In aircraft work a point to be considered always is whether the material will keep its shape and not twist or warp.

In fig. 39 (*d*) a log is shown cut radially—that is,

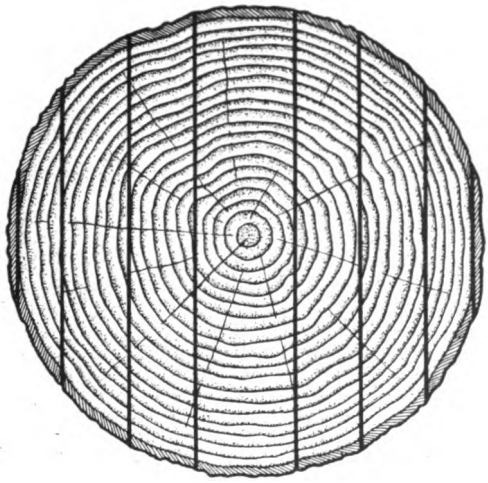


FIG. 40.—Sawing of timber.

the sides are as nearly as possible parallel to the medullary rays and normal to the annual rings. This is known as rift sawing, and is to be preferred.

Fig. 40 shows a log cut by the through-and-through method of sawing. This is much simpler from the sawmills point of view, but it gives a majority of planks which are more liable to warping and twisting. For instance, fig. 39 (*a*) shows a cross section of a longeron which would be obtained

from one of the outer layers of this log after being allowed to stand for some time. The timber shrinks most along the annual rings and to a lesser degree along the lines of the medullary rays. Consequently the outline of the rectangle shrinks as shown by the dark patches. This cannot be overcome, as some people imagine, by cutting the material oversize and reducing it to the proper-sized rectangle afterwards. Timber always shrinks again as each fresh surface is exposed, and consequently the contraction as shown in the illustration reappears after this second operation.

The difference between the shrinkage on a through-and-through-sawn and a rift-sawn plank is shown in fig. 39 (*b*) and (*c*). Bearing in mind the rules for shrinkage just quoted, the reason for the curling up of (*b*) can be easily seen.

It was thought at one time that spars cut so that the annual rings were vertical were stronger than those cut with the rings horizontal, but tests have proved there is little, if any, difference. The latter are obviously preferable from the point of view of their being less liable to warp and twist.

The internal blocks of box spars should also be rift sawn for the same reason.

Struts keep their shape better and will not shrink or bend so much if the annual rings are from side to side, instead of from leading to trailing edge.

Rift-sawn spruce can now be obtained in this country, and should be used in preference to timber

cut haphazard. Large sizes are not often required for aircraft, and it is therefore not very difficult to obtain good planks even from trees of limited size.

It is not always possible to cut ash in the same manner. Ash is rather scarce, and cannot always be obtained straight. In the case of logs which are not straight, use the through-and-through method so arranged that the cuts are straight in one plane. The planks can afterwards be cut into details so arranged that the saw will follow the grain. The success of this depends largely upon the skill and ingenuity of the marker off, who will have to so arrange his templates on a plank that he gets the maximum number of parts out of it without getting an undue amount of cross grain in his finished article. A great deal of valuable wood can be saved by paying attention to this detail and also sometimes by a discreet alteration to the design of a part.

For instance, fig. 41 shows a nose portion of a streamline fairing for a steel interplane or under-carriage strut.

(*a*) shows it worked from one piece of material.

(*b*) shows how a saving of material can be effected by cutting the fairing in halves and making a glued joint up the centre. It also gives a much easier job for the machinist and is less liable to break during manufacture.

Another point which should be watched in cutting up timber for jointing, as in the case of built-up spars, struts, etc., is illustrated in fig. 42.

66903

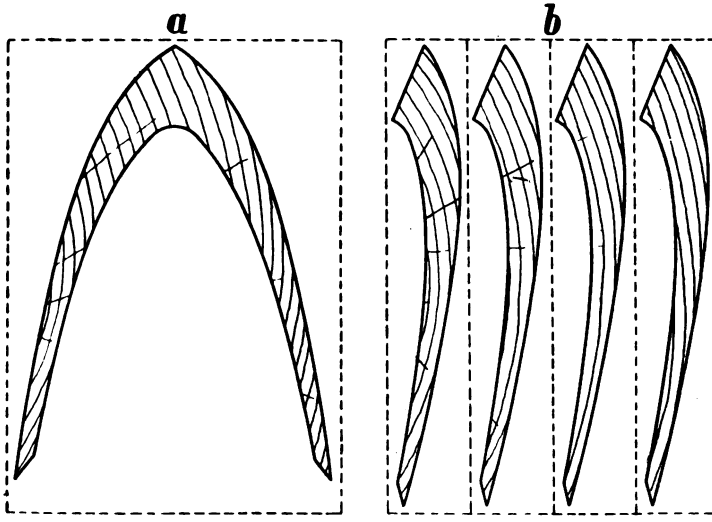


FIG. 41.—Economy of timber.

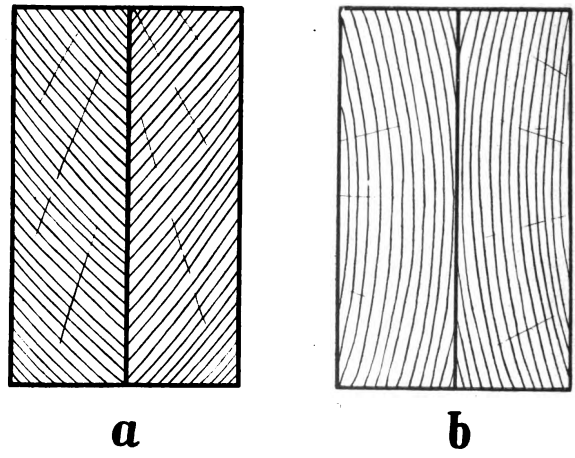


FIG. 42.—Glueing of timber.

(*a*) shows a section through two pieces jointed together with the annual rings at angles of approximately 45° to the joint. By this means the glue is induced to penetrate farther into the fibrous parts of the wood and not to merely remain as a thin layer between the two pieces.

(*b*) shows how this should not be done with the joint tangential to the annual rings, in which case the glue has no chance of percolating down the fibrous part of the rings.

The final conversion of timber into small planks suitable for small details involves very little work not mentioned already.

A specimen of a quantity sheet is given in the next chapter. This would be given to the mill foreman, who draws the timber he requires from the stores and proceeds to cut it up. Lengths are usually cut off by hand or by a cross-cut circular saw. The wood is then taken to the circular saw bench to be cut longitudinally. A roller-feed circular saw suitable for this is shown in fig. 43. It is also known as a radial-feed saw.

(*a*) shows a plank being pushed to the roller which carries it to the saw. Roller feeds usually have four rates of speeds, from 10 ft. to 80 ft. per minute. This machine requires a skilful operator if good even planks are required. The setting of the teeth of this saw also calls for expert attention.

The best machine for heavy planks is the drag-

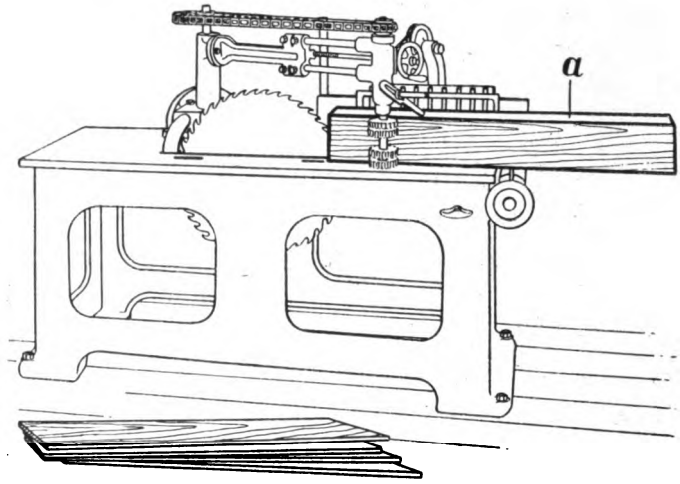


FIG. 43.—Circular saw.

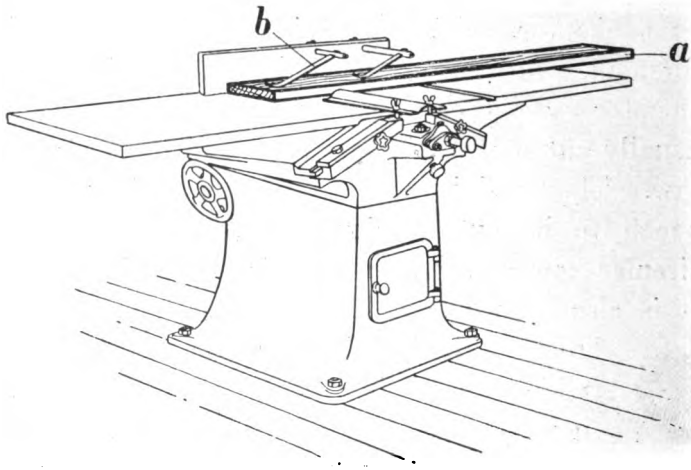


FIG. 44.—Planing machine.

rope feed circular saw. In this machine the timber is pulled to the saw by a long rope, a rope barrel

behind the saw bench winding up the rope and drawing the timber up with it to the saw.

Hand-feed circular saws are also used for small pieces.

Fig. 44 shows a hand-feed planing machine, which is also a necessary part of every sawmill.

(*b*) are the springs which hold the wood (*a*) down on the table. When truing up or straightening parts the springs should not be used, but the wood should be kept its natural shape, so that while passing over the table of the machine, it will be straightened automatically as the cutters remove the high parts.

This machine is used to straighten up the concaved side or edge, and the wood will then be taken to a panel planer or thicknessing machine, where it will be brought to its finished size for the marker-out.

Another machine used for truing up timber is the truing-up machine. This machine has a long travelling table on which the material is laid and carried under the cutters. This machine is only suitable for smaller work, as it cannot be used for any lengths longer than the table.

Another machine is the surfacer and thicknesser, in which one set of cutters is used for both operations, the top table for the truing-up process similar to the one shown in fig. 44, and the bottom table for thicknessing.

CHAPTER V

BUILDING OF SMALL DETAILS IN TIMBER

THE most important operation in the shop with which this description is concerned is that of taking out quantities and setting out work. These duties are usually carried out by one special man to whom all drawings are issued. He then makes up quantity lists as shown from them :—

Type of Machine..... *No. of Components required*, 10.

Component—Top-main Planes.

Part No.	Drawing No.	Description.	No. required.	Width.	Thickness.	Length.	Material.	
				in.	in.	ft. in.		
33	4964	Spar front, R.H. and L.H.	10					
		Flanges, top and bottom	20	$1\frac{1}{4}$	1	17 6	Spruce	1
		Block, 1st . . .	20	2	$1\frac{1}{4}$	1 0	,,	×
		,, 2nd . . .	20	2	$1\frac{1}{4}$	1 3	,,	
		,, 3rd and 4th .	40	2	$1\frac{1}{4}$	0 10	,,	
		,, 5th tip end . .	20	$1\frac{1}{16}$	$1\frac{1}{4}$	0 7	,,	
		Sides	20	$4\frac{1}{4}$	$\frac{3}{8}$	17 6	,,	
34	4964	Spar rear, R.H. and L.H.	10					
		Flanges	20	$1\frac{1}{4}$	1	18 0	,,	

The totals of the various sized pieces of wood are now in a convenient form in the table, and

arrangements can be made to draw the necessary material from the wood stores. This wood will probably be in large pieces, and it is the setter-out's duty to see that it is sawn and planed to the proper sizes. It is convenient to use this list as a simple progress chart, marking it with a line in the end column when the material is past the sawing operation, and a cross when planed.

In taking off quantities, allowance must be made for shrinking and machining, and it should be remembered that much shrinkage often takes place after recessing or spindling.

Consider first of all the manufacture of an ordinary main plane spar. This will cover a series of operations typical of many in the wood-working department.

After quantities are taken off, a spar "rod" (which is the woodworkers' name for a template) should be set out. Obtain a piece of board about $\frac{1}{2}$ in. thick, an inch wider than the over-all width, and 1 ft. longer than the spar. On this a full-size elevation of spar is set out, giving all details of recessing, drilling, and tapering, great care being taken to ensure accuracy. Sections are set out on the same rod, and when thought necessary a plan can be made on the back of it. Care must be taken in this case, however, to clearly indicate which diagram represents the elevation, plan, and sections.

A short piece of board should also be set out as

a template for the cross section of the spar, and passed to the cutter grinder for making his cutters. Using the above rod, a drilling jig must then be made, if needed for large quantities of work, as shown in fig. 45.

This jig should be made of fairly heavy construction in order to withstand the rather severe handling which it will receive in use on the drilling machine. It also needs to have a good wide base to ensure that it will be properly squared up on the machine table.

A spar (*a*) is shown in the jig, fixed in position by the plates (*c*) and (*d*). (*c*) and (*d*) are drilled and bushed at (*b*), to ensure correct drilling for the wiring plates and hinge bolts. The plate (*c*) is held in place by bolts which are removable for taking the spars in and out of the jig. The plates (*d*) are permanently fixed to the jig by wood screws on the top and bottom sides. The bushes in this part are for the drilling of the holes for the external fittings, such as fishplates and strut fittings. The lower plate (*d*) should also be bushed so that the spar can be drilled from both sides where necessary. A pin should be provided to be inserted in the first hole drilled, which will provide a safeguard against the spar moving along inside the jig.

Having drilled the spar, the next operation will be to spindle out the recesses. Some form of spindling jig is required for this. It is best made from a piece of hard wood about $\frac{3}{4}$ in. thick, the

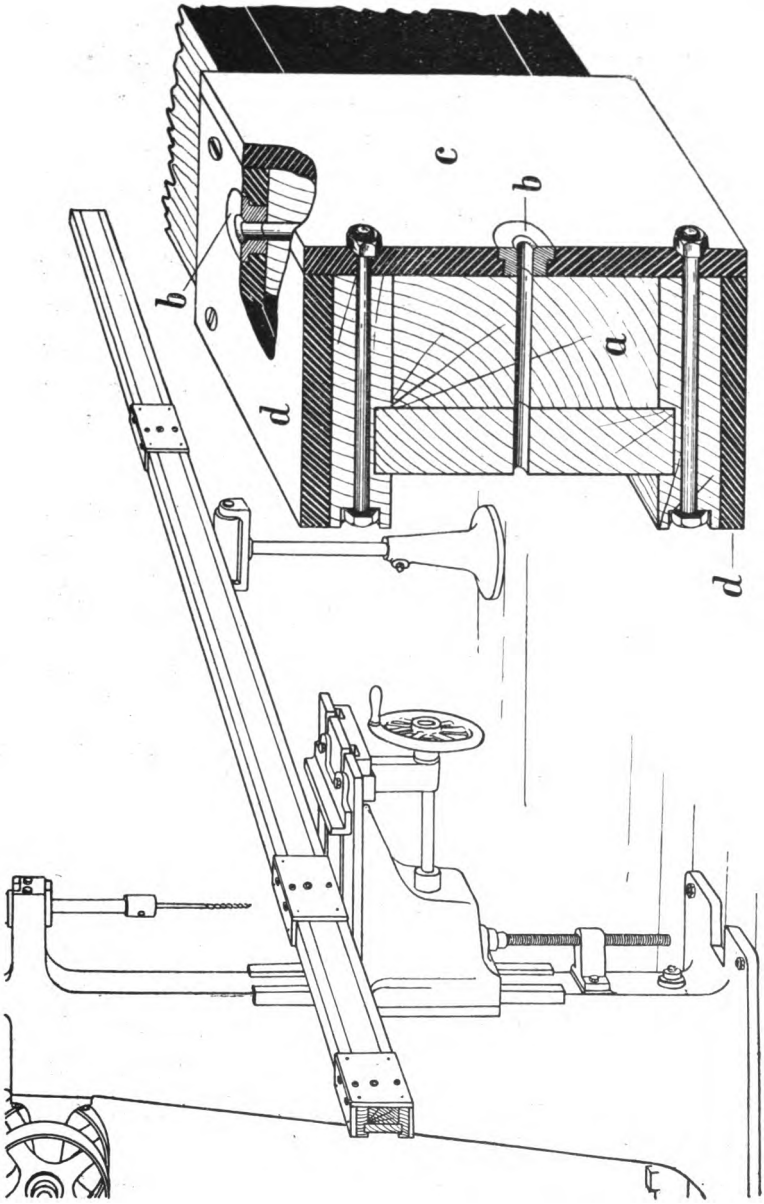


FIG. 45.—Spar drilling jig.

width being the thickness of the spar plus twice the depth of the recess. The shape is exactly equivalent to a longitudinal section, through the web of spar. Blocks are fixed on both sides of the base, where the spar is not recessed, and between these blocks the spar is fixed, resting on the base.

Referring to fig. 46, which shows a French spindle, it will be seen that a spar is being recessed without a jig. The difference here is that between the spar and table of machine there should be the base of the spindling jig. Also behind the spindle there is a bracket fixed, carrying a ring. The spindle revolves inside this ring, which consequently acts as a guard or fence for the jig. It will be seen that the jig, being the shape described above, causes the spar to be pushed away from the cutter at the point at which the recessing is to finish. It should be located by one of the holes drilled on the drilling jig. When this apparatus is used, no marking out of spars is required.

If the number to be made is so small that the expense of making two jigs is not warranted, the following method can be used :—

Each spar is marked out from the spar rods—that is, the marker-out will pencil-mark on the spar itself the recessing and tapering of the spar in width. It will be taken to the band saw to be cut to the tapered outline. The recessing is then carried out as shown in fig. 46.

This is known as a French spindle, and its cutting

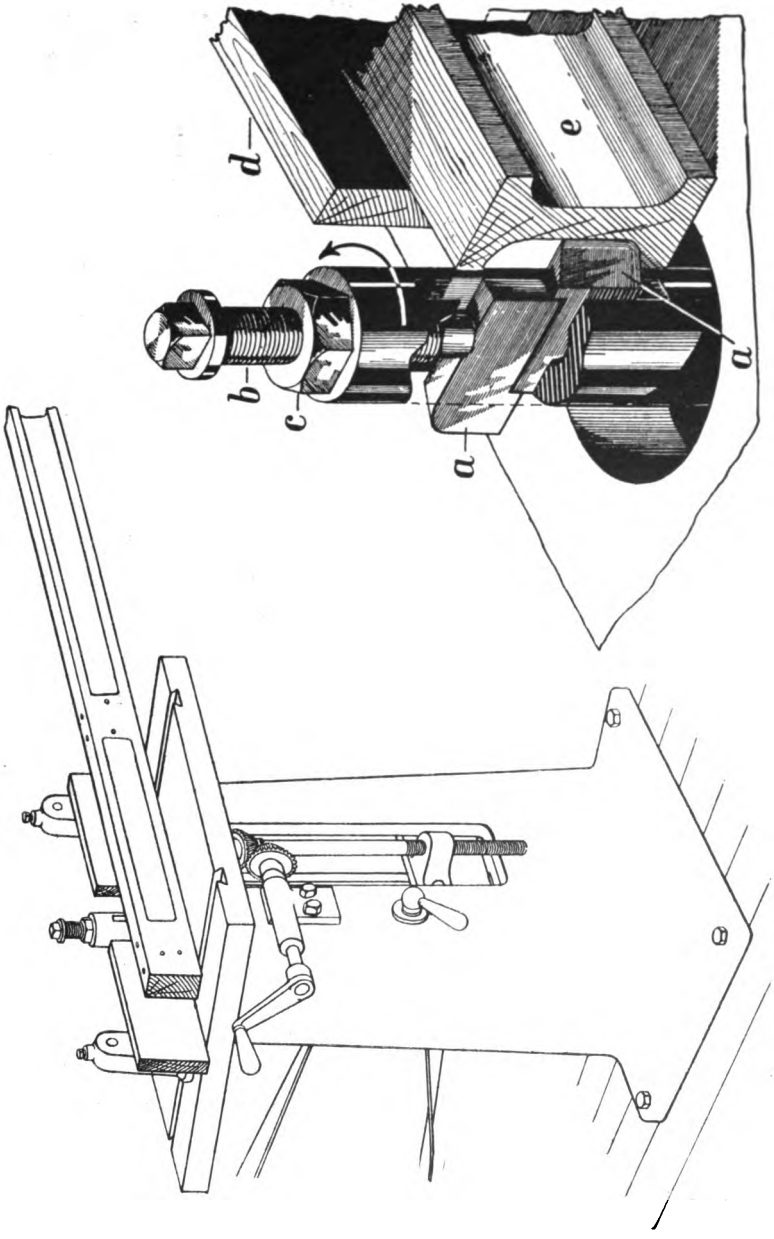


FIG. 46.—Spar spindling

action, in order to form the recesses, is shown in the enlarged view on the right. The cutters (*a*) are made in two halves, mainly for balancing purposes. They are clamped in the slot in the rotating spindle by the set screw (*b*), which is held by the lock nut (*c*). The "fence" (*d*) is set on the table at such a position that when the spar is pressed against it the cutters protrude far enough to remove the correct depth of the recessing (*e*).

After recessing, and while the spars are still square, all drilling should be done, which should be marked off from the same spar rod. The only marking out required for spindling is the end of the recesses, and a gauge-line for the margin. A careful workman is required for this method, as a spar may very easily be spoiled by carrying the recessing along too far.

The spar of hollow form, which is sufficiently popular to-day to call for particular mention here, needs a somewhat different method of construction and design of jig. The actual sequence of operations followed is much the same as that for the solid I-section spar, except that they must be made in halves, known as flitches in the shop, and recessed while in this state.

The marker-out fastens two flitches together with long tacks, picking out the two parts from wood of as nearly the same density and quality as possible. Keeping the best side inside, he then sets them out for recessing, also marking the tips for tapering.

They are then cut, profiled, and recessed just as an ordinary solid spar would be, and passed on to the bench for jointing.

The joiner first takes the flitches apart, and with a small trying plane takes a shaving off the wood where the joint is to be, in order to put a good true surface upon it. He then glues the whole of the inside of the spar, presses and rubs the two recessed faces together, and puts the whole in a press, as shown in fig. 47.

This is an easily made jig for clamping up long spars, either hollow or box shape; the actual spars shown in the illustration are of the

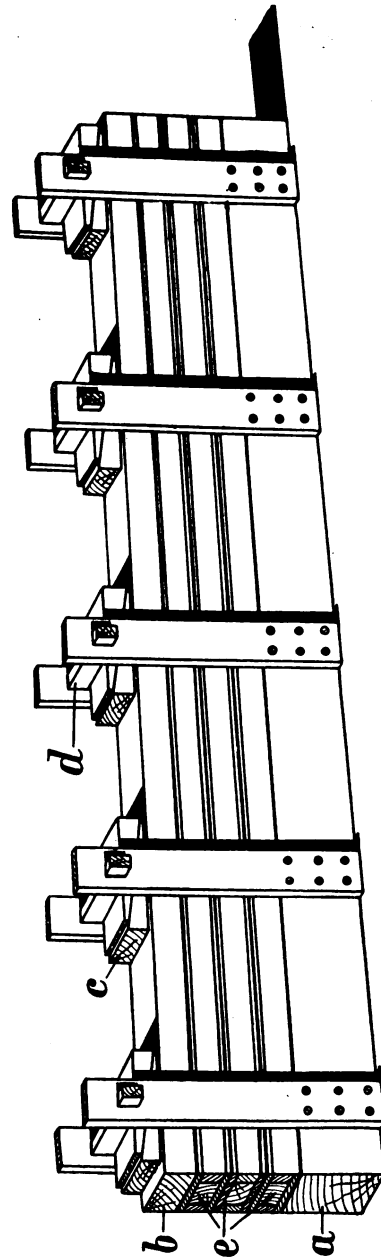


Fig. 47.—Spar glueing jig.

latter type. The base (*a*) must be made of a well-seasoned piece of timber, and must be absolutely straight and level. Upright pieces of wood are fixed on the sides, with nails or screws, and are mortised at top to take cross pieces (*d*). The spars (*e*) are slipped in place, a long piece (*b*) is put on top of spars, and the cross pieces (*d*) are then put in position. Wedges (*c*), as shown, are driven in, pressing the whole together tightly. Care must be taken to locate the solid portions in each half before glueing up, so that they will be exactly coincident. It is also advisable not to allow too much for cleaning off the outside after the spar is glued up, or one of the walls may be left too thin and the other correspondingly thick.

Another type of spar sometimes used is the built-up box spar, as shown in the press in fig. 47 and in the jig in fig. 48.

These spars call for nearly all bench work in manufacture. The blocks can be machined separately. One of these is shown in fig. 48, with the building jig. It is cut off in short lengths marked out with a template, drilled at the inner radius of the recessed portion, and finally cut to shape on a band saw.

These blocks are sometimes made up of a series of horizontal laminations glued together in order to minimise the distortion and tendency to split due to the warping of the wood.

The sides should be cut to shape where the spar

is tapered at the tip, and also, if this taper is at all sharp, the flanges should be bent beforehand.

The process of manufacturing is greatly simplified if these tapers are equally spaced about the centre line of spar in width, and if the spar is parallel in thickness. This is a point which is often overlooked by designers. A jig is shown in fig. 48, for building up these spars.

The base (*a*) should be a well-seasoned piece of wood trued up straight, and without the slightest tendency to twist.

On one edge is fixed a fence (*b*) which locates the

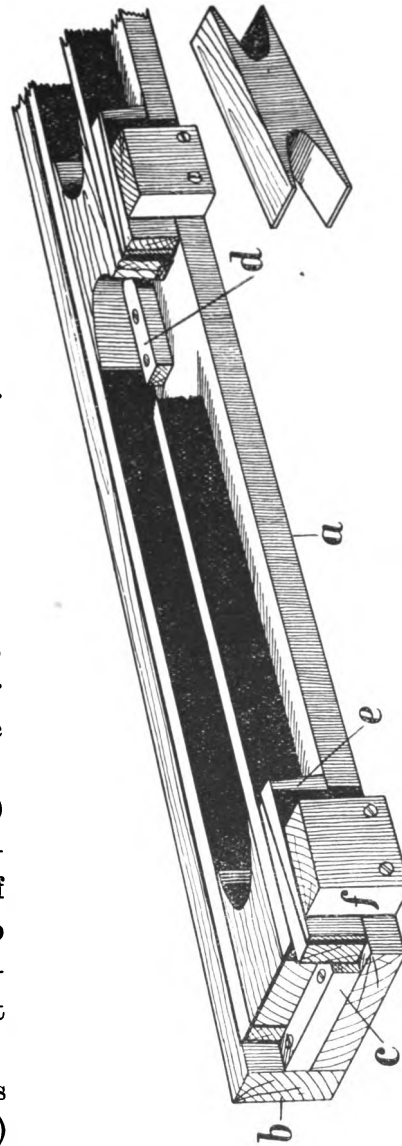


FIG. 48.—Glueing jig for box spars

top flange of the spar; a block (*c*) is fixed at the end also to position the spar end. Blocks (*d*) are for locating the inner packing pieces. These pieces are glued and put into position, the other flange is brought up on the opposite edge of the base, and the folding wedges (*e*) are inserted between the bottom flange and the blocks (*f*). Great care should be taken to see that (*f*) and (*e*) are only used in line with internal packing blocks of the spars.

Sometimes it is thought necessary to lay a long piece of wood between the bottom flange and the wedges in order to distribute the pressure of the wedges more evenly.

When possible, it is an advantage to allow extra thickness on these box spars, for taking off on the planer, as a final truing up before putting on the side plates.

Putting on the side plates is the next operation. This is simply a question of seeing that the joint between the plates and the centre part is well glued, and putting the completed spar into the press, similar to the one shown, to set.

When the glue is thoroughly dry, the spar can be taken out and the rest of the operations, such as drilling, etc., will be identical with those described for solid spars.

The manufacture of fuselage details, *i.e.* longerons, cross members, and engine bearers, etc., calls for very similar processes, with one important reservation.

A fuselage is built up of so many different parts that a final assembly of the first fuselage will often give over-all dimensions varying appreciably from the design figures. It is consequently unwise to prepare the jigs, either for cutting up the material or drilling the holes, until the first one is completed by hand, when the drawings can be altered accordingly.

The manufacture of a wing rib gives an example of woodwork construction which is typical of many in this department.

Rib templates are usually made of $\frac{1}{2}$-in. yellow pine, as this wood stands up to shape well and does not tend to warp or twist to any great extent. From these templates jigs are made both for the machine work and building up of ribs. When making rib templates, it is advisable to check the dimensions of spars, leading and trailing edges, etc., particularly on experimental machines before commencing.

Care must be taken to show all details, as this template becomes practically the shop working drawing, and ribs will be made exactly as shown on it.

It is sometimes wise to show a plan on another board, in cases where the flanges are shaped. These should all be numbered up to correspond with the drawing numbers, and the greatest care taken of them.

Where ribs are built up in girder form and the

flange and web form a T section, the following methods are used :—

Flanges are grooved on the spindling machine with a jig, which consists of a board to which the flanges are fixed. Several flanges can be grooved at one time if the jig is made wide enough.

Projections are fixed to the board, to push the work away from the cutters where no groove is required. The spindle can also be fitted with a jig to cut the flanges to width, and groove them at the same time, out of thin boards planed to the thickness of the flanges. Several different methods may be adopted for cutting the webs for these ribs. One way is to order up the wood to the required thickness, and make a marking-out template.

Lay the material in bundles of about six, according to the thickness of the wood, and with the template mark out the top surface of the bundle. Nail the pieces together with panel pins, the pins being put in so that the pieces will remain in bundles all through the machining. These will be taken to the band saw and cut (see fig. 55, for band saw) and then taken to the spindle to be profiled. Fig. 49 shows a jig for profiling one portion of the rib. Spaces for two operations are required on this, shown at (*a*) and (*b*) respectively.

The slot (*a*) is used for the first operation, the space here being larger than that at (*b*) by an amount sufficient to allow for the material to be

trued up at (*b*). The bundle is then transferred to (*b*) and finished to the shape as shown at (*c*); (*d*) are wooden buttons, used for fixing the work in the jig.

Instead of this jig a template can be used, made

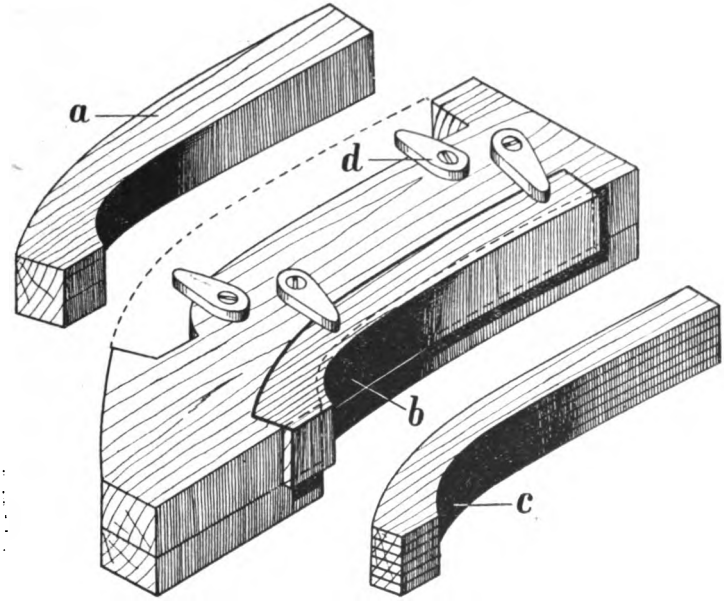


FIG. 49.—Spindle jig for profiling rib webs.

of hard wood $\frac{1}{2}$ in. thick and about 1 in. longer than the finished article at each end.

This should be tacked on the top of the bundle, and used against the ring of the spindle instead of the base of the jig. This method is useful when only a small quantity are required.

Another method is to order up the material thick enough to cut a number out of one piece,

instead of tacking the pieces together. The solid piece should be marked out, cut on the band saw, and profiled, using the same kind of jig. They can then be cut to thickness, using a dimension saw. If this saw is well sharpened, the finished webs will need no cleaning up. This method has the advantage that there are not a lot of unnecessary nail-holes, as would be caused by tacking them together.

When ribs are very long, and the web laths only about 1 in. to 1¼ in. wide, it is possible to bend these and glue them to the flanges before building up instead of machining them as just described.

A simple jig is required for this job. Take the rib template, and mark either the top or bottom edge on a board for a base. Fix on the outside of this line a fillet, or several small blocks. Then cut out three loose pieces—one for the leading end of rib, one for between the spars, and the other for the trailing portion. These pieces must be grooved to hold the web, their thickness must be the same as the width of the flanges, and the groove must correspond with the groove in the flange, also being deep enough to hold the web in position. Large wooden buttons are used to bring these pieces up to the flange, forcing the web into the groove in the flange, and fixing it until the glue is dry. In this case the parts are first marked out for the band saw, then profiled on the spindle, after which

they will be marked for recessing. It is only necessary to mark the ends of recess in this case. Fig. 50 shows a typical template for this. It is first used for marking for the band saw using the edges (*c*). The holes marked (*a*) are used for marking ends for recess which appears on the finished ribs shown at (*b*). This marking-out is

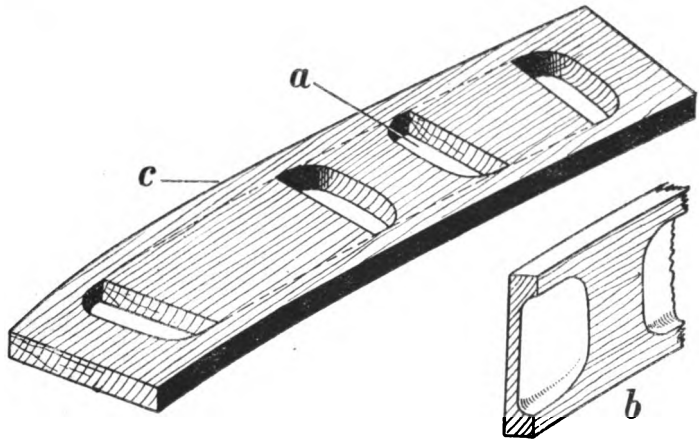


FIG. 50.—Marking-out template for solid rib spindling.

done after profiling, and at the same time it is convenient to mark the ends for cutting off. End ribs and compression ribs are sometimes made solid and recessed to form the webs.

A spindle template for profiling this job would be similar to this one. This should be made of hard wood $\frac{1}{2}$ in. thick and 1 in. longer than the job at each end; otherwise the shape is the same, but without the holes (*a*). This spindle template is fixed to the piece to be profiled, by a small nail at

each end. The template and the ring on the machine keep the piece of wood at the correct distance for the cutter to remove the required amount. If the depth of the recess is not parallel with the face of the work, a jig may have to be made. This will simply require a form of box to lay the member in, with the sides shaped inwards to keep the bottom of the recess equidistant from the spindle of the machine.

This class of work is also done on a recessing machine, which requires a different type of jig. In the table of the machine is a hole for a stud directly under the centre of the spindle. Make the jig out of a piece of plywood $\frac{3}{8}$ in. or $\frac{1}{2}$ in. thick, and cut a hole in this the shape of the recess; but the size must be governed by the difference between the radius of the stud and the radius of the tool. If they are equal, the hole in the jig will be exactly the same as the recessed part of the work.

Fillets are fixed on the plywood, to hold the pieces being recessed in position. This jig is laid on the table with the stud in the hole, the piece of work is laid in the jig, the tool brought down to the depth of recess and fixed. The jig is then worked round the stud, while the tool is taking out the recess.

Another kind of rib web in common use is a solid one with lightening holes cut in it. When these are thin, several can be tacked together for working. The marking, cutting, and profiling are done as

described before; when these holes are large, a special tool has to be made for the recessing machine. For elongated holes it is usually simpler to drill at each end, with drills or tools giving the proper radii, and then cut out the remainder with a

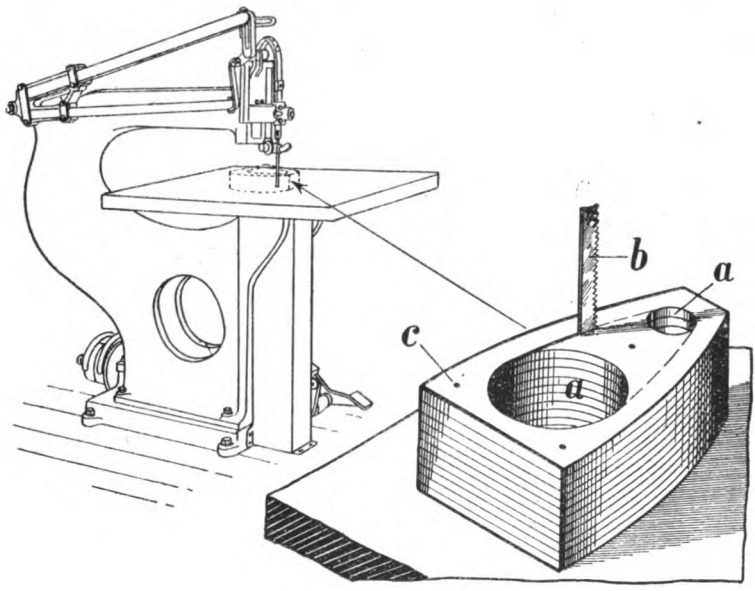


FIG. 51.—Fretsaw

fretsaw. Fig. 51 shows a fretsaw cutting several of these webs in one bundle; the holes are drilled as at (*a*), (*b*) shows the saw, and (*c*) shows the pins holding the pieces together.

Having considered the manufacture of the various items used in the making of a typical rib, it will now be convenient to pass on to the actual building up of the completed article.

Jigs of some kind must be made for assembling ribs. A useful type is shown in fig. 52. The base (*a*) should be a well-seasoned piece of wood about 2 in. thick, of width and length to suit the ribs. Plenty of room should be allowed for the buttons (*c*) and blocks (*d*) to be manipulated. First fix a rib template temporarily to the base (*a*), and then to the edge of the template on one side fix on the blocks (*d*) with glue and panel pins or screws. On the other side screw on the buttons (*c*). These must be made to turn round on the screws, as they are used to clamp up the flanges. Both (*d*) and (*c*) should be as thick as the width of the flanges. Blocks (*b*) are then put in place to represent the spars, and must be fixed on to the base securely. Blocks are also necessary for the trailing and leading edges. The block for the leading edge has been omitted from the drawing for the sake of clearness.

The process of building a rib in this jig hardly needs any further explanation, being perfectly clear upon reference to fig. 52, where a partly erected rib is shown in position.

Another process which enters largely into the work of this shop is the bending of long and comparatively narrow strips of timber into various curved forms.

Artificial bending of timber is necessary for two reasons: one the saving of material; and the other is that bent timber is stronger than material cut across the grain, which must happen if segments

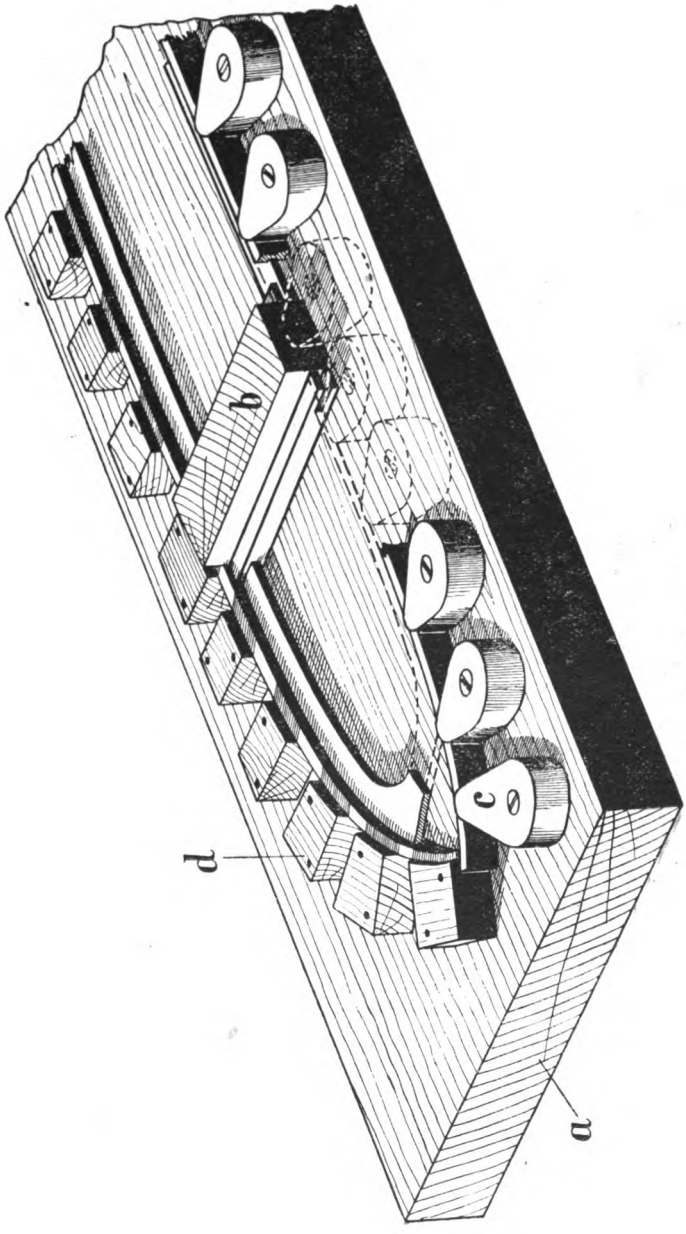


FIG. 52.—Rib erecting jig.

are cut out of straight-grained timber. Timber bending is made possible by the fact that heat and water have the power to penetrate wood and make it soft and pliant.

One method is to place the wood in boiling water and leave it until soft. Another method is to make a steam chest, which is simply any form of box moderately steam-tight. This is often made of wood, and will do quite a lot of work. It must be fitted with bearers across the inside to rest the pieces for bending on, and the bearers must be so fixed that they will allow the steam to circulate round the wood. The steam is usually taken from a small boiler in the vicinity. The temperature should not exceed 220° Fahr. (2 lbs. per sq. in. pressure). Under the above conditions it will take from two to three hours for the steam to penetrate ash 1 in. square in section.

It is found best, when bending trailing edges, or similar parts which are bent across the widest way of the section, to cut up and bend the material of sufficient width to make two. This will bring the material for bending more nearly square in section, under which condition it will bend round more truly. When bending edgewise the material is very liable to turn over, and the job will not come out well.

For large objects it will make a better job if they are laminated along their length. The laminæ should first be steamed and bent, and allowed to

dry on a former such as is shown in figs. 53 and 54. The bent laminæ are then glued together and put back on the former to dry and set. This method will also be found useful even on small sizes where bends are very sharp, as the pieces will keep their shape better and not be so liable to crack during the bending process.

When bending spruce, this method of lamination should always be used. If the laminæ are thin, it can generally be curved without steaming. A jig for this class of work will be external and internal—that is, one to fit inside the piece of work and one outside of the correct radii. When these are clamped into position, all the glued joints will be held tight while setting.

No allowance need be made for the work going back to its natural shape under these conditions. Where the bends are not laminated, it is necessary to make some allowance for the wood tending to spring back towards its natural shape. The amount required is governed to a certain extent by the length of time that the work can be left on the jig. A return of one inch for every foot of displacement from the natural shape should be sufficient under ordinary conditions working on a line normal to the curve all the time.

Fig. 53 shows an easily made jig for bending timber. The former (*a*) is built up of two pieces about 1½ in. thick, with battens nailed across; upright pieces are fixed on the sides, with a hole

mortised about 6 in. from the top end, to take the cross pieces (*b*). These are used as a support for the folding wedges (*c*) when forcing the material on to the former (*a*).

Another type (fig. 54) is a jig with which good results have been obtained. The former (*a*) will have to be solid as shown. A strap (*b*) is fixed

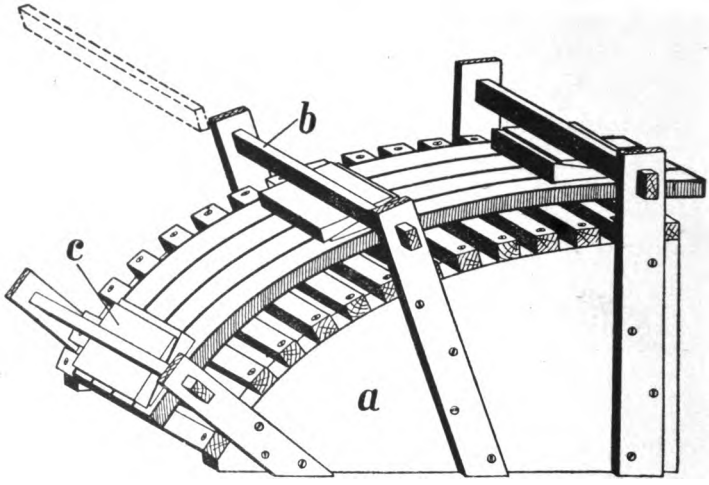


FIG. 53.—Bending jig.

at one end, where the bending starts. The end of piece for bending is put in (*b*) and wedged by (*c*).

A bending lever (*d*) as shown works on a bolt whose centre is the same as the centre of radius of bend. A roller (*e*) is fixed in the lever, its position being adjustable to take various thicknesses of wood. A thin strip of iron should be laid on the wood so that it will not be damaged by the roller.

At the other end is a similar strap (*b*) fixed with

a bolt. This is swung over after the wood is brought down into position, and wedges are used to hold it until the work is set. If the job is very long, it may be necessary to have more straps. In that case a pin similar to the one shown on the lever must be used for fixing the intermediate straps.

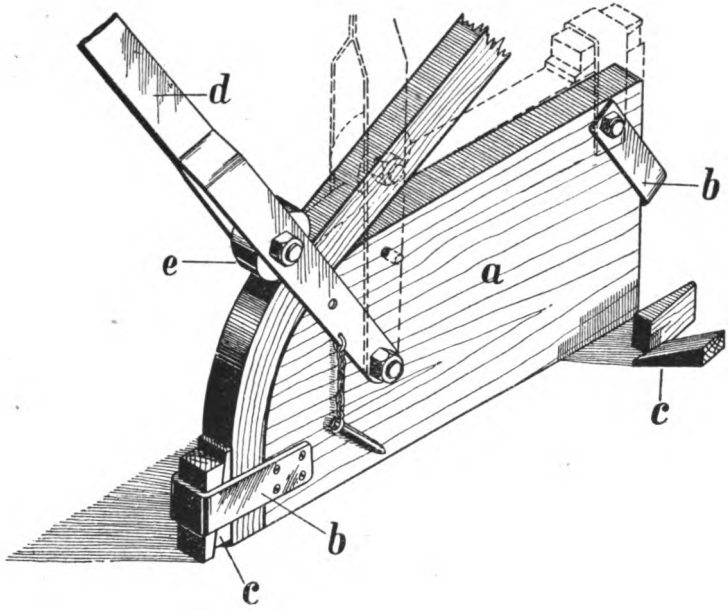


FIG. 54.—Bending jig.

For small bends a jig can be devised, by fixing the former on to a piece of board for a base and using strong G clamps to force the wood into position.

The manufacture of wooden interplane struts is another job calling for some special mention. A template is made giving the profile, the exact length and section, and from this the spindle

template is made as described in the explanation of rib building.

The struts are cut roughly to shape first on the band saw (fig. 55 shows this operation), afterwards

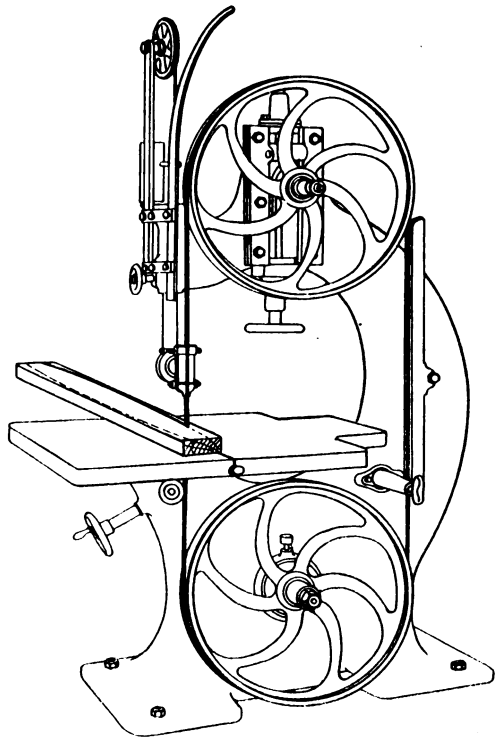


FIG. 55.—Band saw.

profiling on the spindle. Then if a jig is made for holding the strut, it can be brought down nearly to shape on the spindle, and finished on the bench by hand, section templates being used to bring it down to correct size and shape. These are pieces of

wood, hollowed out to shape so as to fit the outside of strut. The dimensions should be left full to allow for cleaning up with sandpaper. A copying lathe can also be used for strut turning. In that case a steel former is required which is the same shape as the strut. This method would be used only if the quantity were sufficiently large to warrant the expense of making a set of steel formers for the machine.

For cutting the struts to length a box should be made, in which the strut is laid, with saw cuts at each end for the saw to work in. The cuts should have small pieces of mild steel plate fixed on either side to keep the saw from gradually eating its way into the sides of the slots while cutting off the struts, and thus altering the over-all length.

This box or jig is made in the following manner. A base is required, and on this a piece of wood is fixed on either side with room for the strut to lie between them. It should be about 6 in. longer at each end than the strut itself, and must be provided with packing blocks sufficient to keep the strut level and also its centre line parallel with that of the box.

CHAPTER VI

WOODWORK ASSEMBLING-SHOP WORK

THE class of work dealt with in this shop will be so varied that it is impossible to cover it in a chapter of this size. The processes described here will be confined to the erection of a typical fuselage, a plane, and an aileron. These should be sufficient to indicate the general procedure of a shop of this description.

The fuselage chosen is an ordinary rectangular braced construction, with longerons and horizontal and vertical cross members of rectangular cross section. These cross members are held in position on the longerons by metal fittings, which in turn take the cross bracing wires to complete the structure.

The first operation will be to fit the metal work on the top and bottom side members. If these fittings are well made and jig drilled, there is no reason why the woodwork should not be drilled before coming to the assemblers. Fig. 56 shows a jig (*c*) for assembling the metal parts and, at the

same time, fitting and making a splice, such as might occur on any average small machine. A base is obtained, large enough to carry the posts, which take the place of the vertical side members, and will locate the fittings. Small clamps (*a*) are

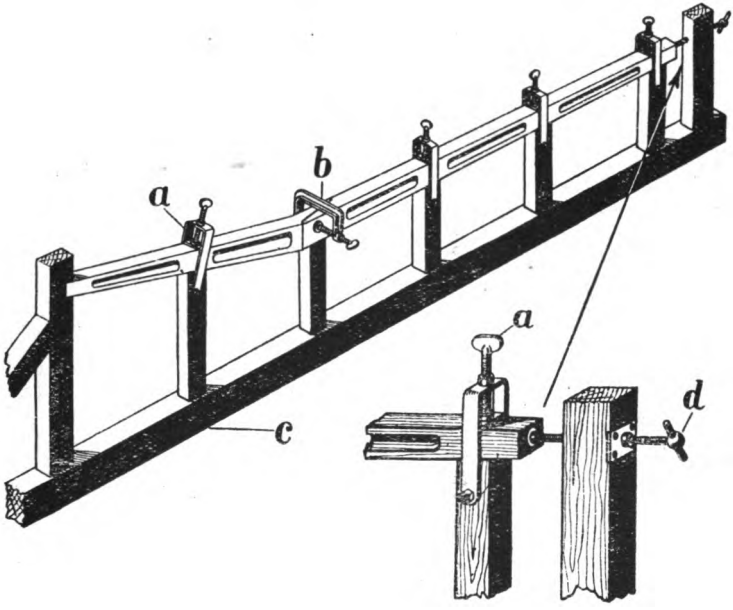


FIG. 56.—Jig for glueing spliced fuselage member.

made for holding down the fittings, while the drilling and fixing is being done. This is a good opportunity for making the splice at the same time, the operator being able to see all round the joint. Under these conditions a good fit is ensured, and the longeron fitting can afterwards be put in place before the joint is disturbed. The screw (*d*) at end is for tightening the joint endwise, and the G

clamp (*b*) for pressing up the joint crosswise. The small clamps such as (*a*) are used to keep the member on the jig, and they are removed one at a time as each metal fitting replaces them.

The next operation will be the assembling of a complete side. A suitable jig for this is shown in fig. 57. The base (*a*) is a flat board made of good stout plywood, if it can be obtained, as this is thoroughly seasoned and less likely to warp. Set out the side elevation of the body on this, working with extreme accuracy. Mark out the centre lines first with the aid of a sharp knife, and then trace the outlines of the wooden members about these. The wooden positioning blocks (*c*) can now be screwed and glued in place. The position of these requires a good deal of thought, bearing in mind the particular function of each. The introduction of unnecessary blocks should be avoided, but, on the other hand, it should be remembered that one pair in the middle of a member is not sufficient to fix its position alone. For instance, in fig. 57 two pairs of blocks are provided for each vertical member for this reason. One pair in each bay are quite sufficient for the top and bottom longerons, as they are continuous from one bay to the next.

The holes in the base (*a*) have now to be cut as shown at (*b*); these are necessary in order to give room for drilling and bolting up the metal fittings. Plenty of room should be given in the hole (*b*); otherwise the operator will be handicapped.

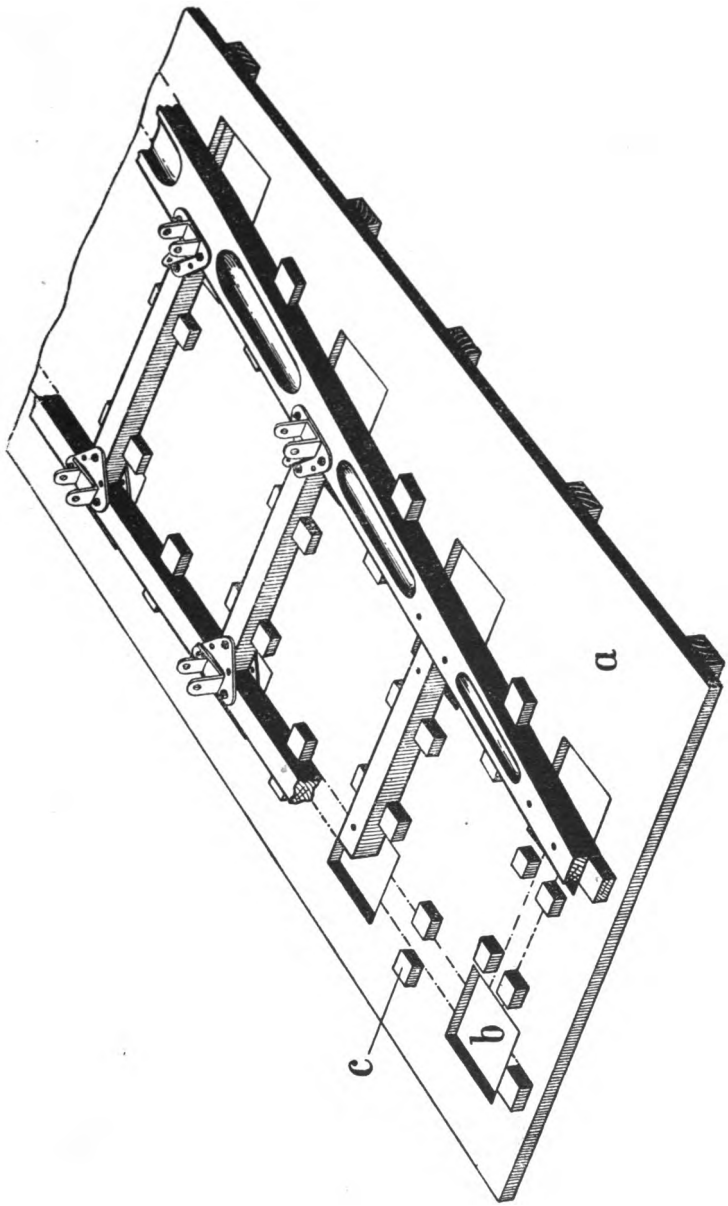


FIG. 57.—Jig for main frame.

Several joiners' clamps as shown on the jig in fig. 58 will be necessary for holding the joints in order to ensure that the ends of the struts are properly bedded on to the longerons before drilling the holes for the fittings. The straining wires or the tie-rods must then be put in place in order to keep the sides square. It can now be removed from the jig complete and ready for erection into a complete fuselage. This jig should be made with a similar set of blocks on each face of it, so that the fuselage sides can be built on either face. The sides will come off right- or left-handed according to which face is used. The faces should be clearly marked R.H. and L.H. in order to avoid confusion when making spare sides.

In some shops this type of jig is built up on a framed structure, using any well-seasoned wood of about $1\frac{1}{2}$ in. thickness. This is probably more economical in the first cost, as smaller pieces of wood can be used up; but it has the disadvantage that a framed body is more liable to distort slightly, especially if stacked away for a time with other heavy bodies resting on it. For obvious reasons a jig upon whose dimensions absolute reliability cannot be placed is worse than valueless.

When a number of sides have been fitted up, the operation of building them into complete fuselage must be taken up. Fig. 58 is a jig for the assembly of these sides into a complete body. The base of this jig should be a framed piece as shown, and on

one side of it a post should be fixed at each end with a rail at the top to stiffen the posts and keep them in position.

These posts and the rail can be used as datum lines from which measurements to various parts may be taken for checking purposes as erection proceeds. A number of wooden blocks shaped to

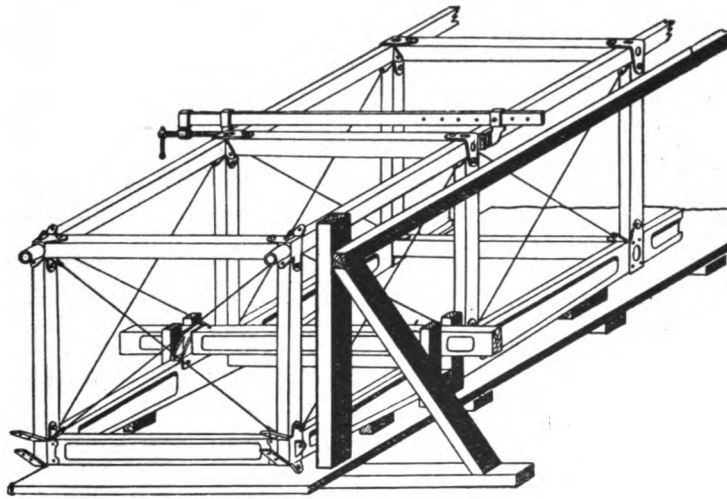


FIG. 58.—Jig for erecting fuselage.

support the bottom longerons are screwed to the base at intervals—one in the centre of each bay,—and two small posts are fixed to serve as a location for the bottom wing spar fittings. The construction of this jig can be clearly seen on fig. 58.

Erection is commenced by placing one side on its supporting blocks and fastening it to the posts. The other side is then brought up, and the cross members put into position. A joiners' clamp is used,

as shown, on each joint while drilling the holes for the bolts in the cross members. It will be necessary to have several of these clamps at the same time on this jig as on the previous one, in order to ensure that one clamp being tight on the part being drilled is not causing the adjacent portion of the longeron to bulge out.

The question of drilling holes for the metal fittings should also receive special attention when jig erection is used. The fuselage, being fixed to the jig, cannot be readily transported or tipped up to various angles under a drilling machine. It is therefore necessary to use a portable drill of some kind, which makes it absolutely imperative that some device should be adopted to ensure that the drill enters the wood members in a direct line with the hole in the metal fitting. A simple form of jig for this purpose is shown in fig. 59, fixed in position on a longeron with a vertical member in its place against it. The jig has the shape of a G clamp with a screwed plug (*a*) for gripping it in position on the job.

This plug is fixed when tightened up, with lock nuts (*b*). The pin (*c*) positions the jig on opposite side. This pin is first placed in the hole in the metal fitting, and the drill passed through the hole in (*a*). Then screw down (*a*), fix with the lock nut (*b*), and drill the hole through (*a*). The drill, being guided by the comparatively long hole in the plug (*a*), will be bound to emerge from the wood member

truly opposite to and in line with the lower hole in the metal fitting.

The body should come off this jig complete and ready for assembling to the rear part. Both of these jigs would be used for production of large quantities.

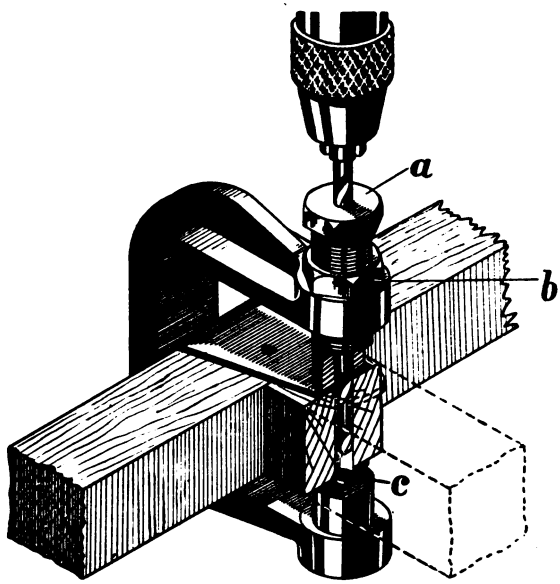


FIG. 59.—Drilling jig for frame joints.

For experimental work such jigs would not be required to the same degree of elaborateness, although some device for holding the individual parts during erection should still be provided. In this case it is usual to set out a side elevation of the body on a wide board, and on this the sides are built up one bay at a time. When this operation is completed, it is quite simple to put in the

cross members, the body being set up on a bench to do this.

Careful measurements, comparing it with the drawings, must be taken during this process, and also the fuselage must be constantly checked for alignment and squareness.

The remaining operation in the completion of a fuselage is the assembling of the two halves. No jig should be necessary for this if the workman who makes the joints in the longerons is reasonably efficient.

The front portion should be set up absolutely level and square on a surface plate. A piece of wood is now fixed across the front end in such a position that a small saw cut can be placed at the exact centre of the fuselage. The centre of the end of the rear portion is similarly marked, and a string is stretched across these after the two portions are brought together. This string thus becomes the theoretical centre line of the fuselage, and the joints in the longerons have to be made in such a position that this centre line passes through the middle point of each bay. Other fittings, such as fin posts, rudder, and tail skid connections, which can be located from this line, are usually fixed in position at this stage.

The "monocoque" type of fuselage is now becoming increasingly popular owing to the fact that it gives a clear interior without cross bracing wires, thus being more convenient for either

passengers or the carrying of goods. This type would obviously require a rather different jig, but the principle underlying its construction would be the same. Supports and positioning blocks must be so arranged that every part automatically falls into its place without calling for any special measuring or laying out on the part of the operator. The jig usually consists of a cradle upon which the lower sheet of three-ply is fixed. The ribs or box-formers are then fastened to this, being located by suitable arms rising from the cradle. The horizontal stringers are then attached to the ribs, and finally the outer covering is screwed in position.

The erection of a wing from details whose individual construction has already been described can now be conveniently considered. Fig. 60 shows a typical jig for this purpose.

(*a*) are the longitudinal pieces, forming the base of jig.

(*b*) are cross pieces hinged to these so that they locate the spars, but can be dropped to allow the ribs to pass along.

(*c*) is an end piece, forming a buttress for end of the spars and also the end rib, at the inner, or fuselage, end of plane.

(*d*) is a stick for spacing the ribs.

(*e*) is a pulley arrangement for pulling the ribs on from the wing tip ends of the spars.

The bars are framed together, or fixed to some cross pieces on the underside, and the whole can

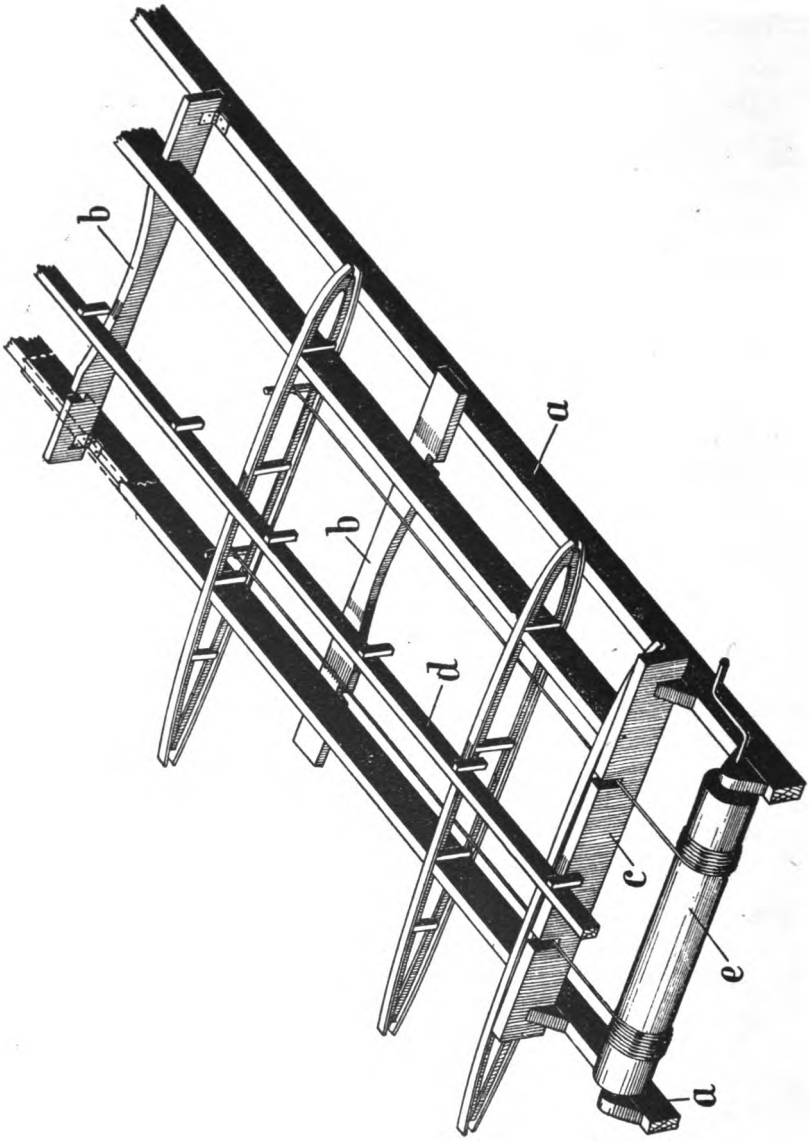


FIG. 60.—Erecting jig for planes.

be laid on trestles or a bench. Each cross piece is hollowed out on the top, to allow the cross bracing wire to pass over. The spars, ribs, and bracing wires only are put together on this jig, and the construction is then passed on for fixing leading and trailing edges to another jig.

Fig. 61 shows a small clamp suitable for such a jig for fixing the trailing edge in position in the ribs.

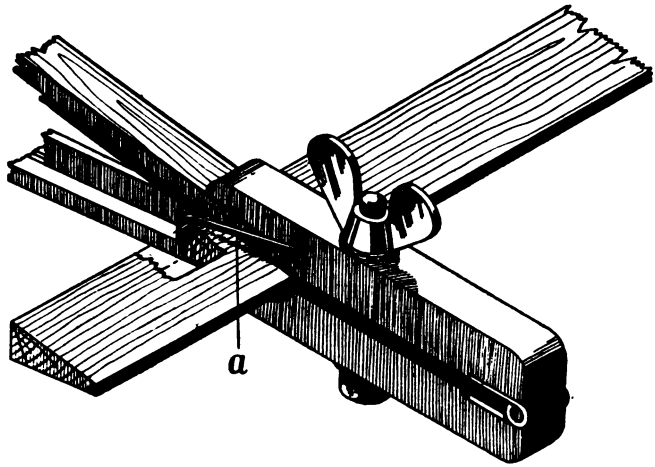


FIG. 61.—Glueing clamp for leading and trailing edges.

(*a*) is a metal strip to keep the clamp from slipping back while being tightened up.

Similar ones can be used on the leading edge. The action of these is to draw the flanges of the ribs down tight on to the edges after glueing, the clamp remaining until the glue is set. It is then removed and the screws inserted. This makes a better job than drawing down the flanges by means of the screws without clamps.

The planes should then pass on to another bench for wing tip edges and wing tip ribs to be assembled. This will mean specialising in labour ; but it is usually worth while, as it will get the work out quickly where a number of machines of one type are required.

If only a small number of one type is required, the bench itself should be used as a jig with similar cross pieces to (*b*) (fig. 60), screwed to it, care being taken to fix them in such a way that they will clear the ribs.

The end piece (*c*) will also be needed to fix the ends of spars.

These pieces must all be fixed up on the bench absolutely square, with the notches in the cross pieces (*b*) in line. In this case these notches must be large enough for a wedge to hold the spars in position and the plane generally square, as the final adjustment will be made from the drawing by the aid of a rule. The roller (*e*) is not required in this case.

The leading and trailing edges can be fixed in this same jig, also the wing tip edges and bracing wires, checking over the measurements while proceeding. Internal wiring plates and bracing wires can be assembled more easily before fixing the leading and trailing edges, and in this case it is necessary to leave the compression ribs loose until after the wires are adjusted and the wiring plates fixed.

A small jig or gauge should be used to test the position of the holes for strut fittings and fish plates.

A gauge for testing the spar centres is also useful, and if each of these is carefully used no trouble should be experienced during erection of the machine.

Gauges for packing pieces, if called for at the strut ends—one to give the height above each edge of spar, and one to test the overall dimensions of packing,—are necessary to ensure correct assembling also.

Great care must be taken when putting in the internal bracing to keep an even tension on the wires, or unnecessary strain will be induced in the spars and compression ribs with disastrous results.

There are several ingenious devices for measuring the amount of tension in bracing wires when tightening up the turnbuckles, but they are unfortunately the type of instrument which belongs to the laboratory rather than the workshop, being not only delicate but also somewhat slow in application.

Ordinary common-sense judgment is generally sufficient to prevent overtightening or leaving the wires too slack, either of which is an equally serious fault. Some erectors make a practice of "twanging" the wires, a combination of the "feel" of the wire and the note given out telling them when the correct tension is obtained.

Another important point to watch is that the

centres of all hinges for wing flaps or ailerons must be in line if the flaps are to work properly. These should be tested before being fixed with a fine cord stretched through the holes, and adjusted accordingly.

Final testing for truth both as to dimensions and squareness is best done with the trammels or beam compasses. If these have a good stiff beam, they can be used for dimensions up to about 12 ft. long. The centres for squaring can be taken from the vertical holes in the spars, and the test made by measuring the diagonals with the trammels. This is very necessary, as when taking the planes out of a jig they often spring a little and need a small final adjustment.

Tail planes can be built up in the same way when they are in two components; but when they consist of one continuous plane only, the jig must be made to locate from the centre instead of from one end. If the spars have all been drilled, locations from these holes can be taken.

Rudders and fins, if built in wood construction, need very similar treatment.

A useful jig for assembling ailerons is shown in fig. 62. This type would be used for quantity production of small machines of one type.

The stand (*d*) is built up in trestle form and fixed on a bench. The jig itself (*c*) is fixed on a trunnion, as shown on the enlarged view, so that the aileron can be worked on both sides without taking it out.

The aileron spar is first held on the base of the jig by means of tongues similar to (*a*). These tongues represent the hinges, and will vary in form, depending upon the type of hinge used on the planes. This artifice is adopted in order to ensure that the aileron will be fixed in the jig during erection at exactly the same points as it will be in use, viz. at the hinges. This is a particularly important point to bear in mind when thinking out a design for a jig for parts such as this.

The ribs are located by the flap hinge (*b*), which is hinged so that it can be dropped down, while sliding the rib along and glueing it, and brought up again for finally locating the rib, before screwing it. The jig is slotted out at (*e*) for ease in inserting the screws at the trailing edge.

The rib should be drilled for screws, and the flanges should all be trimmed off to length before coming to this jig. The similar one on the opposite side of the trestle is provided in order that the ailerons may be made in pairs, right- and left-handed.

A jig similar to the above can also be used for elevators. It is also possible to build ailerons and elevators on jigs similar to the one described for fuselage sides previously. The suitability of any particular type of jig must obviously depend upon the design of the part to be made, the equipment of the shop itself, and the class of labour to be used.

When producing small quantities only it will be

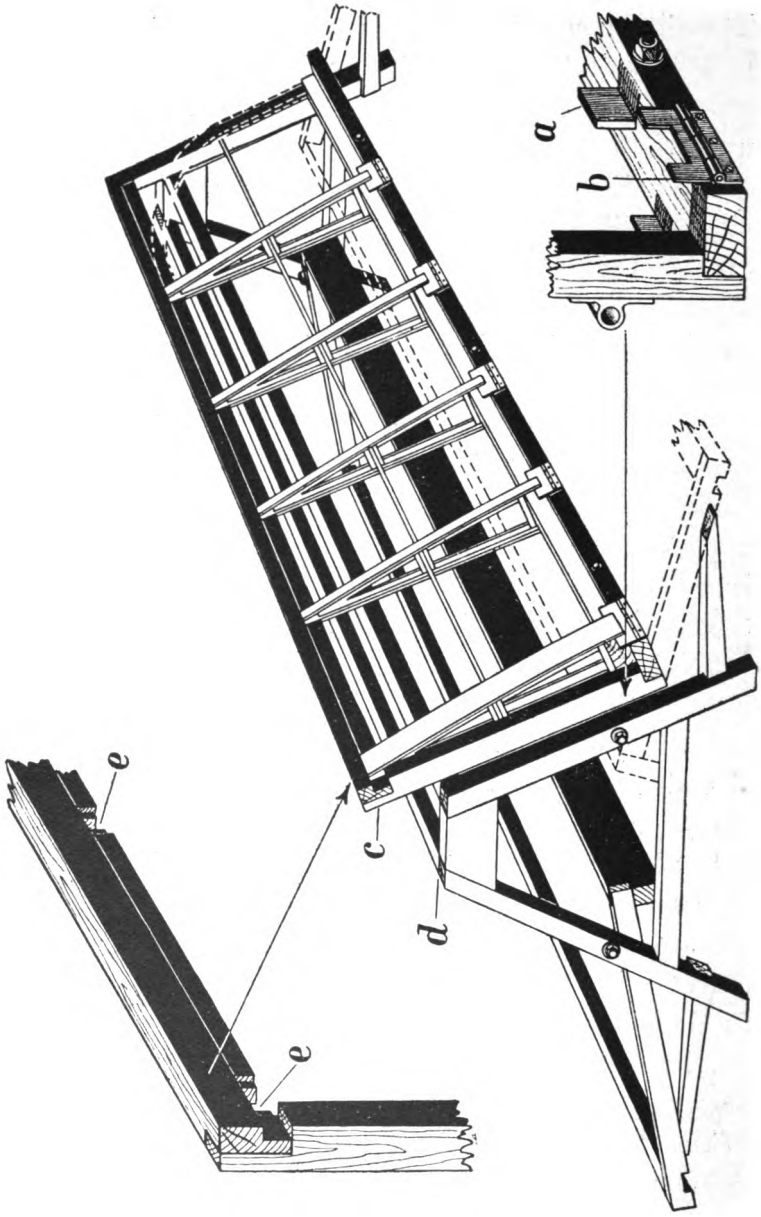


FIG. 62.—Erecting jig for ailerons.

sufficient to make a frame similar to the jig (*c*) and to fix it to a bench so that the ribs of the aileron are vertical. The base in this case should be about $\frac{1}{4}$ in. wider than the spar. Cut notches in the base and in the top rail of jig, for locating the ribs. Wooden buttons should be fixed to the top rail over the notches to prevent the ribs from falling out.

The ends of the ribs should be about 3 in. above the top rail of jig, in order to give plenty of room for fixing the trailing edge. Two blocks will be needed on each side of the base to fix the spars in place. The ribs are pushed on the spars, being located by the notches in the base and top of the jig. The stringer, if called for, is then pushed through, and afterwards the trailing edge. The joints are best glued as the different parts are assembled. One side is then screwed together, and the aileron taken out of the jig and the other side screwed up while lying on the bench. In this case it is best to leave the ends of the flanges of the ribs long and cut them off after assembly. This is a simple and effective jig for experimental machines where only small quantities are called for.

The assembling of interplane struts, when made of wood, should also be carried out in this shop, and is an operation which perhaps needs a short explanation, as it is somewhat different from any of those already described.

The ferrules are first fitted to the ends of struts, and a gauge, similar to the one shown in fig. 63, is

used for testing the length. These ferrules are pressed up in a clamp, care being taken to see that the ends of the wooden strut are properly bedded down into the socket, and then fixed in the gauge.

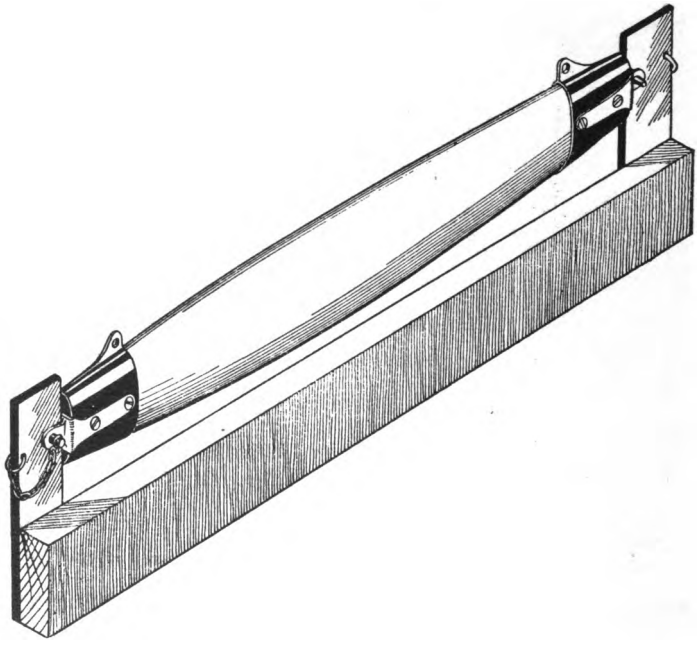


FIG. 63.—Strut checking jig.

The drilling for the bolts, or tubular rivets, is done, and the bolts fixed or the ends of the rivets spun over, on a drilling machine with a special tool, while still in position on the jig. The gauge is simply a piece of wood with two pieces of mild steel plate screwed on, as shown.

The precaution of attaching a pin of the correct size to the jig as shown on this drawing is one that

should always be observed. Otherwise the pins are bound to get lost sooner or later, and others of an incorrect size substituted.

Even a discrepancy of only a small fraction of an inch in the diameter of this pin will be sufficient to allow the distance between the centres of the holes in the ferrules to vary enough to ruin interchangeability in these struts.

CHAPTER VII

BUILDING OF AIRSCREWS

AIRSCREWS as used on aircraft may be divided into four distinct classes—R.H. tractor, L.H. tractor, R.H. pusher, and L.H. pusher. A tractor is one which is fitted in front of the wings; a propeller or pusher is one which is placed behind. A right-handed airscrew is one which, when viewed from behind, rotates in a clockwise direction. A left-handed airscrew is one which when viewed similarly, rotates in an anti-clockwise direction.

Before going into the detail on the construction of airscrews, the student should make himself thoroughly conversant with the foregoing and with the terms most commonly used such as "pitch" and "diameter."

Pitch is the axial distance which would be travelled by the airscrew in one revolution, if there is no "slip."

Diameter as measured is the diameter of a circle which would just pass over the tips, and whose centre is the centre of the boss.

The materials used are invariably walnut and mahogany in this country. Combinations of these together with ash, birch, white oak, maple, etc., have been resorted to, but cannot be said to have given satisfaction. All airscrews are now constructed on the laminated principle, *i.e.* a number of laminations varying from $\frac{3}{4}$ in. to 1 in. in thickness held together by glueing the surfaces and also sometimes driving hardwood pegs through them. This construction calls for a very high degree of reliability in the glued joints, and particular attention has to be paid both to the process of glueing and the manufacture of the glue. It is probably no exaggeration to say that there is no branch of the woodworking industry which has made more rapid strides during the late war, under proper scientific study of its details, than that concerned with the making of glued joints.

The construction of a propeller or airscrew to a particular design must be carried out on a highly systematised plan, the various operations being interdependent. They may be set down roughly as follows:—

(1) Set out airscrew, and make all templates.
(2) Selection of planks to form each lamina.
(3) Planing of plank to required thickness.
(4) Roughing of planks to shape.
(5) Drying.
(6) Balance laminations.
(7) Glueing up.

(8) Clamping.
(9) Pegging (when called for).
(10) Boring of boss (first operation).
(11) Rough shaping.
(12) Finish boring of boss.
(13) Finish shaping and balancing of airscrew.
(14) Coating with filler.
(15) Varnishing.
(16) Tipping (when called for).
(17) Balancing final.
(18) Testing.
(19) Marking.

Taking the operations in turn, it is necessary to first give attention to the templates, the actual construction of which is dependent on the quantity of airscrews required to the particular design. Where a large number are required, it is usual to employ thin sheet metal for them. These are of two types, lamination templates and form templates. Taking the lamination templates as shown in fig. 64, first of all, a sheet of metal should be painted and the exact shape of the lamination marked out on it. This must then be cut to the lines and the edges smooth. This is followed out for the remaining laminæ, the templates being afterwards numbered according to their corresponding drawing.

The main centre line of the blade, and also a line at right angles to it through the centre of the boss, should be clearly marked on each template, as it is necessary to transfer this line to each

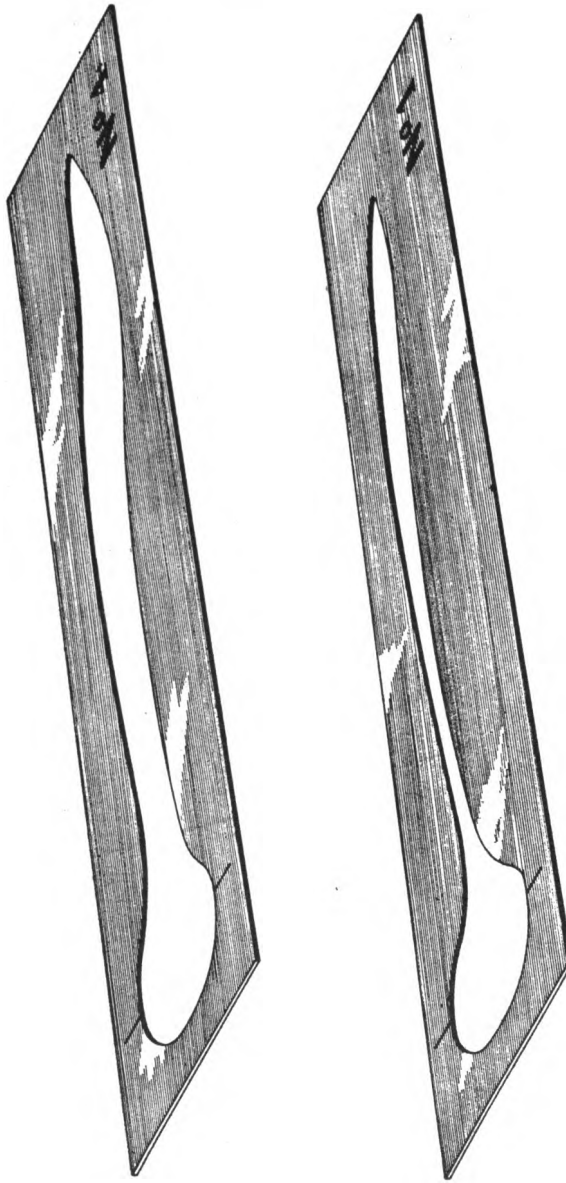


FIG. 64.—Lamination templates.

wooden piece cut from it, to be used when assembling them for glueing up.

Form templates, which are used to obtain the correct outline of the airscrew at various points, are of two types. A simple one is sometimes made of a light steel plate, riveted or otherwise secured to a heavier piece to form a base (see fig. 65), in which case it is usual to make the base so that the form plate is readily removable by the addition of the set screws shown.

The outline of one face of the propeller either in the "pitch face" or "the back" is reproduced on the edge (*d e*) of the steel plate, and this edge is constantly "offered up" to the blade as the shaping process proceeds. This type of template calls for two plates for each section of the blade to be measured.

A more popular kind is shown in the lower drawing (fig. 65) which combines the two faces in one template.

It consists of two plates (*a*) and (*b*), having a square base not shown in the drawing, one of which has the addition of two pins (*c*) to form stops for the other. The rough propeller is shaped down until the pins just reach the bottom of the slots when the template is slipped in place. It will be found, on reference to the drawing, that the designer has divided up the length of the blade with a number of ordinates lettered *a a*, *b b*, etc., dimensions being given between each. A sectional view taken

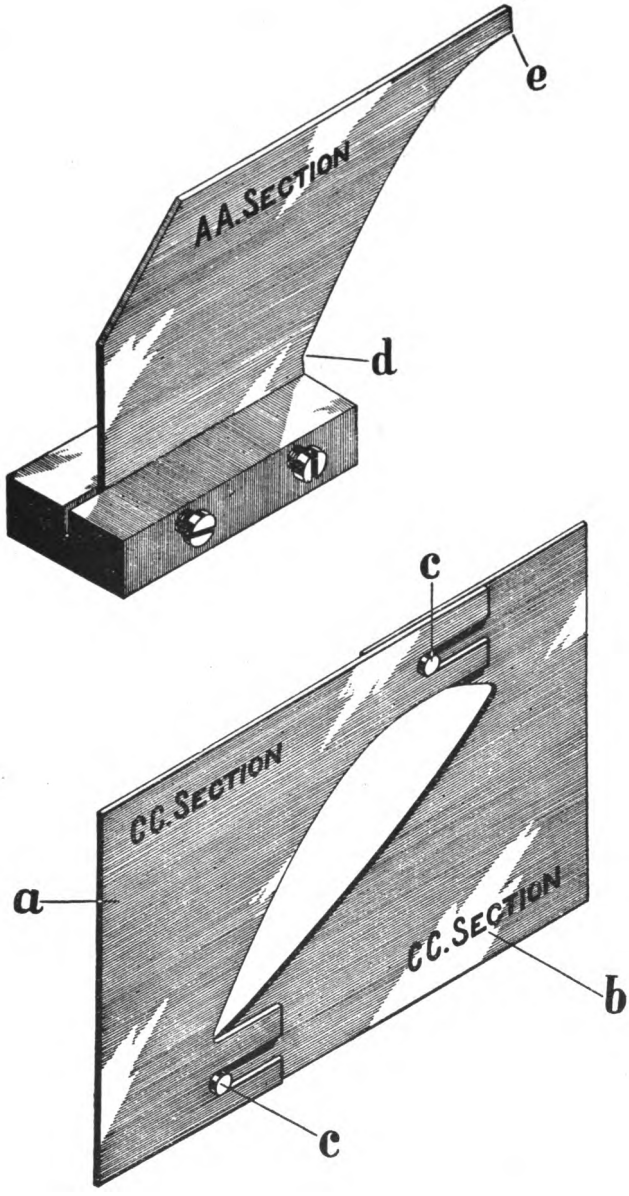


FIG 65.—Form templates: base type and plate type.

through the blade at each of these is given, which should set out in the fullest possible detail the dimensions of the cross section at this point. These are the figures to which the outlines of the form templates just described have to be made. Each template should be clearly marked with the letters *a a* or *b b* and so on, showing which section it represents.

In the case of only a single experimental propeller being made, it is usual to let the propeller maker lay out and make his own templates in wood, care being taken to construct these in such a manner as to obviate the effect of shrinkage as far as possible. They should then be checked for accuracy by an independent person capable of pointing out any errors which may have occurred either in the dimensioning of the drawing or the transferring of the same to the templates, who should mark them according to their corresponding ordinate *a a*, *b b*, and so on.

The selection of planks of walnut or mahogany for airscrews should be carried out with great care. Select a plank according to the width and thickness required, and inspect for defects such as shakes and knots, etc., also for any signs of incipient rot of any kind.

It is here as well to point out that samples of the stock from which the selection is made should have been tested for general properties, such as tensile strength, compressive strength, bending

strength, and hardness. Weight should be as nearly constant as practicable, and not more than 40 lb. per cub. ft.

Before proceeding with the roughing-out of the planks to shape, they should have the outline marked on them from the lamination template to serve as a guide. They can then be placed on the table of the band saw singly and sawn roughly to the line. Having cut out the required number of laminæ, the whole batch should then be suitably stacked to ensure the correct degree of dryness.

It is usual to store them for two or three weeks in a room in which the atmospheric conditions and temperature are as nearly corresponding to those of the glueing-room as possible. Special precautions should be taken to exclude dust and draughts and to maintain a constant temperature of not less than 70° Fahr. It is well also to again roughly inspect for defects and to see that the grain runs parallel to the surfaces as far as possible, and also directly lengthwise.

The laminæ should now be lightly planed by hand, to the final thickness, and a suitable glueing surface made on each face. The surfaces of each piece should be toothed with a fine veining plane to add to the efficiency of the joint.

It is as well to carry out a preliminary balancing operation upon each lamination at this stage. Fig. 66 shows a machine used for this purpose. The frame, in this case arranged to bolt to a wall,

carries two ball bearings (*a*) which support a spindle (*b*). In some cases the spindle runs on knife edges instead. Each lamination is mounted on the spindle in turn, and a balance is obtained by clipping a small weight on to the lightest end. This end is then

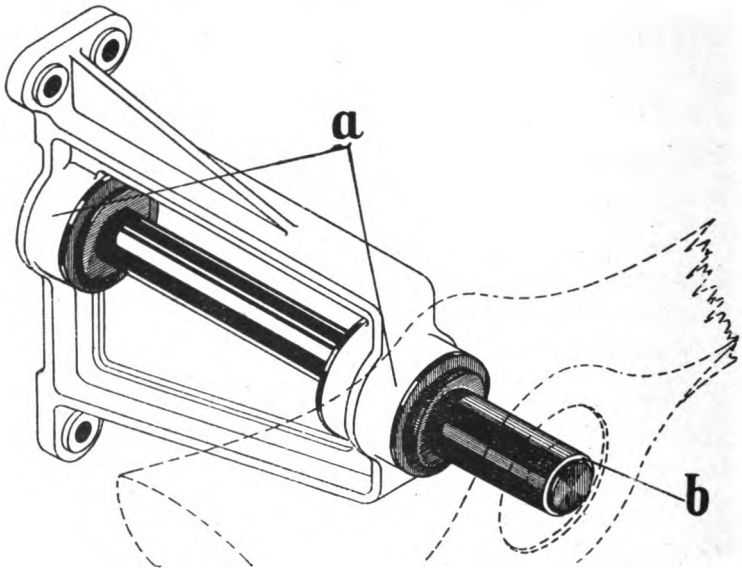


FIG. 66.—Balancing spigot on wall bracket.

suitably marked so that when the final assembly of the layers, during glueing, takes place, they can be so arranged that a light end of one piece is placed on the opposite side of the boss to the light end of the next piece.

The laminæ should now be stored in the glue-room for at least twenty-four hours, previous to glueing up, which must be done in a room kept at

a constant temperature of between 70° and 100° Fahr. The laminations, previously roughly cut to shape and arranged to give the required section, should be clamped down in pairs after glueing. The glue is applied hot and as rapidly as possible. The pairs are then left to dry under pressure with clamps for about twelve hours, after which pairs of pairs are glued and clamped, and so on until all the laminations are glued together. The assembled mass should then be securely clamped and left to set for about three days. The strength of the air-screw being dependent on the glue joints, the importance of thoroughly clamping cannot be over-estimated. The clamps should be placed about 6 in. apart and the pressure applied evenly, fixing the centre one first and then working outwards towards the tips. It is also possible to glue up the whole of the laminæ in one operation if proper attention is paid to assembling the parts quickly before the glued surfaces have become chilled. In this case the pieces should be warmed up in a separate chamber to about 100° Fahr., and several assistants should be available for coating the surfaces with glue. The process should be so organised that each glued face has about three minutes' wait for the glue to penetrate before it is placed in contact with the next one. The whole operation, including the tightening up of the clamps, should be completed within ten minutes of first applying the glue.

A number of different types of glue are in common use, but liquid or jelly glues are not encouraged for this class of work, as they usually contain a large amount of carbolic acid. It is preferable to use a cake glue made to an approved specification which generally conforms roughly to the following:—

(*a*) Raw material, to be hide glue only.

(*b*) Phenol content, not to exceed 3 per cent.

(*c*) Melting-point, 31° Cent.

(*d*) Resistance to moisture. A film of the glue (hard) immersed in water at 25° Cent. should not become liquid before twenty hours have elapsed after its immersion.

(*e*) Strength, 1200 lb. per sq. in.

Especial care should also be taken with the preparation of the glue, and on no account should continuous boiling be allowed. A sufficient quantity of stock for one day's use should be made up by adding the proper quantity of water, and portions of it heated as required.

Fig. 67 shows a jig for glueing up the laminations into the final block. The centre clamp (*a*) is held by a bolt which passes through the centre hole of the boss. This clamp is adjusted first of all. The other clamps are shown at (*b*). The top caps of each of these are screwed to a board (*e*) which serves to distribute the pressure evenly over the whole propeller and also to keep the clamps at their correct spacing. (*c*) is the glueing bed, made of a

good stout piece of board about 3 in. thick. On either side of the airscrew pressure blocks (*d*) are

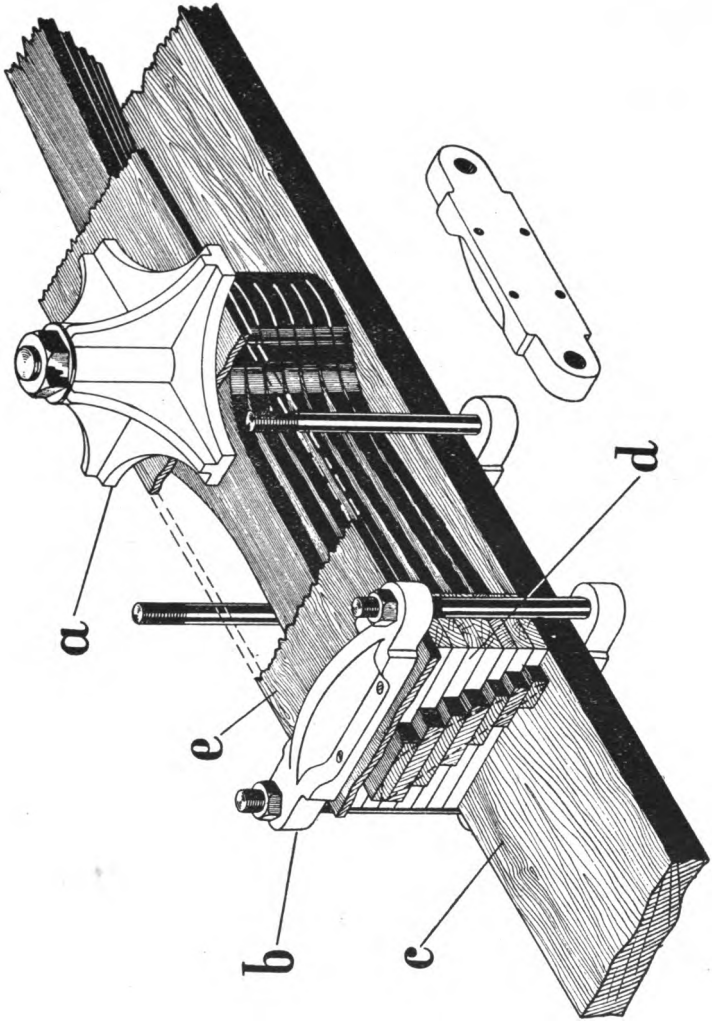


FIG. 67.—Propeller glueing clamp.

placed, whose function is to grip each lamination and prevent the work from tipping sideways.

The airscrew is now ready for pegging. This consists of drilling holes and driving small hardwood pegs about $\frac{3}{16}$-in. diameter.

The necessity for these pegs, whose function is to prevent one surface from sliding over another, is debatable nowadays, in view of the improved methods of glueing. They have the disadvantage that they must be very carefully fitted into their holes. If too loose, they are apt to fall out; and if too tight, they start a split from the hole while being driven in, which is bound to develop into a dangerous crack sooner or later.

The next operation to be taken up is the boring of the hole, which fits on to the engine hub, in the centre of the boss. Some makers prefer to bore a small hole of about 1-in. diameter to suit the spigot upon which it will have to be mounted in the machine used for the following operation of rough shaping. The final boring is then carried out after this shaping is done. This is a somewhat longer process, as it necessitates two boring operations; but it is more reliable, as the work of shaping the propeller subjects it to fairly severe strains and the hole is liable to become distorted. This distortion can then be corrected when carrying out the final boring to the finished size.

However, there are still manufacturers who prefer to complete the boring to the finished dimensions at this stage, and—provided that the operator of the shaping machine understands that he must not take

too heavy cuts and so unnecessarily strain the airscrew—there is no reason why this system should not be followed.

The screw is next shaped roughly to the form template. This is sometimes done by hand, but more often, where quantities permit, by machine. In the first case the ordinary woodworker's tools are employed, and it is therefore essential, wherever possible, to employ machines on account of the laborious nature of this work. Special machines have been designed for this, the most popular being "Wadkin's" propeller shaper, the underlying principle of which is the "former."

It consists of a cast-iron bed having a former of the exact shape of the blade fixed in a suitable position, and carrying a framework having two overhanging arms, the bottom one of which has a roller which rests on the former. In operation this roller follows the shape of the former and, moving parallel with this, the top arm carries the cutter, driven by a belt. The whole is fitted up with a series of springs, which are arranged so that when the cutter reaches the outer edge of the wood, it returns smartly to its original position, and, moving alone the line of the blade, repeats the operation.

This machine is an absolute necessity where airscrews are made in quantities, the saving in time and consequent reduction in cost being a considerable item. The airscrew is fixed in a machine of

this type by placing it on a spigot which fits exactly into the hole through the boss which has been previously bored out. Reversing the airscrew on the spigot, the shaping can be completed.

The boring of the hole in the boss has now to be finished off, if not already done. The greatest possible care should be exercised over this operation. If the hole is not a good fit on the engine hub, vibration is set up, which is dangerous with a propeller running at anything from 1000 to 2000 revolutions per minute. The hole must be perfectly round, smooth, and at right angles to the faces of the boss. Also the recess or radius at each end must be of the correct size, so that it will fit on to the corresponding one on the engine hub. It must be borne in mind that the hole needs to be a good push fit on the hub after being painted. Therefore it should have a little clearance at this stage. One half-millimetre is the allowance usually given for this.

The holes in the boss of the airscrew which take the engine boss bolts should now be drilled to suit, after which the boss should be given a coat of red lead or other waterproof paint.

After at least four days have elapsed since the rough shaping, the airscrew may be finished off by hand, care being taken to remove the material evenly and to balance the blades. When the blades are shaped by hand, the usual method is to mark the ordinates along the blade and cut to the corre-

sponding template. Great care is necessary in doing this, thin strips of steel down to ·003-in. thickness being employed to expose any discrepancy between the shape of the blade and the template. The remainder of the blade is then cleaned off until a smooth even surface in accordance with design is obtained.

The final smoothing-off is done in conjunction with the balancing spigot. This is a wood or steel spigot on ball bearings fixed to a wall bracket, upon which the airscrew is placed. Material is removed until a perfect balance is obtained by sand-papering.

The balancing spigot shown in fig. 66 has already been described. The airscrew is mounted on this, and the blades are finally finished until they are so nearly equal in weight that the propeller will remain at rest in any position in which it is placed. On no account should lead plugging be used for this, as the presence of isolated pieces of metal in the blades sets up unequal strains when revolving at high rates. If a blade is considerably out of balance, wood may be removed by sand-papering or scraping from the pitch face of the blade only. It is much better to obtain the same result by giving additional weight to the lighter blade by the addition of more "size" or "filler," the application of which forms part of the finishing process. This method, of course, can only be adopted when the discrepancy in weight is not too great.

The next operation is the covering of the entire

surface with a substantial coating of good wood filler, consisting of flaked lead, putty, colour, and turpentine, which, having been allowed to soak in, is rubbed down with a cloth, after which the airscrew should be allowed to stand and set for about twenty-four hours. The blades are then given two or more coatings of good copal varnish, being rubbed down after each coat with powdered pumice. The final coatings (three in number) of finishing varnish are then applied, and during this operation the airscrew should be constantly checked for balance, and adjustments made by adding extra varnish where required.

Owing to the constantly increasing stresses which airscrews are expected to withstand, it has been found necessary to protect the outer ends of the leading edges, also the tips, by means of a metal or fabric cover. The latter is securely glued on to the entire surface of the blade to within approximately 12 in. of the boss; in the case of the metal tip, however, it is not necessary to carry the protection so far, the real intention being merely to protect the outer extremity of the leading edge and the tip. This is done by making a sheath of the same shape as the plane at this point and securely screwing the same to the blade.

This sheath, shown on fig. 68, may be either in brass or copper, and presents some difficulty in its manufacture, chiefly on account of the extremely thin metal used, 24G brass not having sufficient

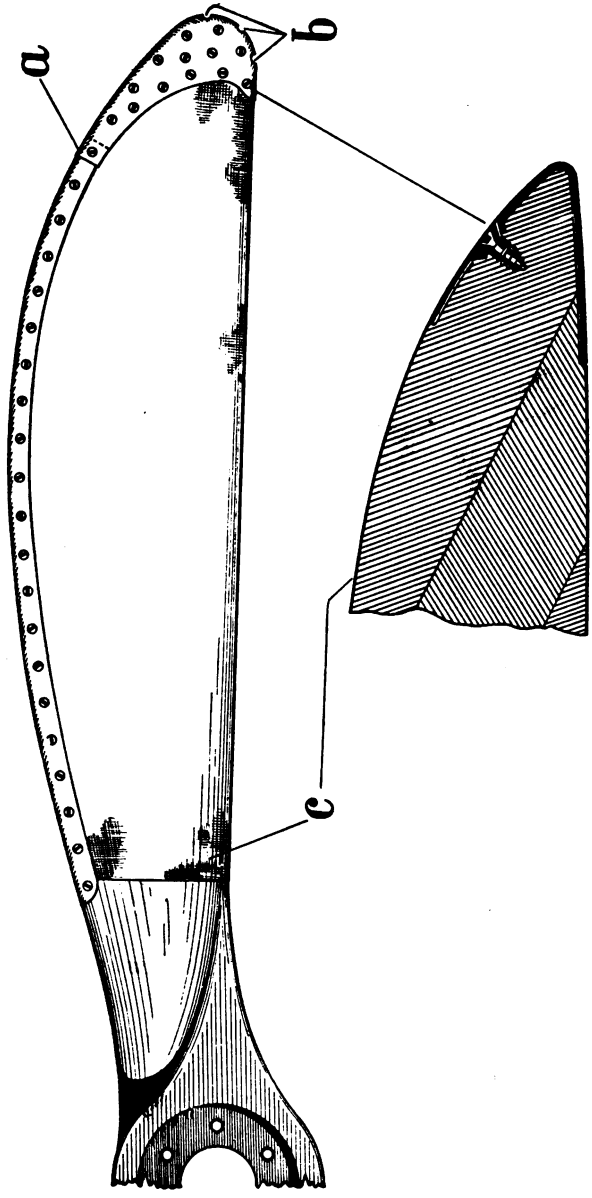


FIG. 68.—Metal tipping.

substance to enable a good joint to be made by ordinary soldering; consequently the joint is silver-soldered. The rivets must be driven in below the remaining surface of the sheath, the consequent slight indentation being overcome by covering the head of the rivet with silver solder and filing off evenly. The position of this joint is shown at (*a*).

The metal tip is let into the blade flush with the surface, and has three small indentations adjacent to its extreme edge to serve as drainage points for moisture, which may collect on the tip when the airscrew is in use. The chief difficulty in the manufacture of the metal tip occurs when making the joint between the two sides. Ordinary solder has not sufficient strength to be serviceable, therefore hard or silver soldering is resorted to. This is carried out on similar lines to soft soldering, the difference being in the use of an extremely high grade of solder. This can be purchased at prices up to 6s. per ounce, according to the prevailing price of silver, which is the chief constituent. Especial care should be taken to ensure a thoroughly clean metal, and the heat must be directed on to the joint until the solder runs freely. The forming of the holes to take the screws calls for special attention. An enlarged section of one of these is shown on fig. 68. A small hole is first drilled, and the metal is then "spun" or "punched" in, so that it forms a cup for the head of the screw to rest in, thus assisting the screw in holding the sheath

down. Each screw head is finally soldered in position, and they should be carefully cleaned, especially in the saw cut, before insertion, in order to simplify the soldering operation afterwards.

The fabric covering is shown at (*c*) in fig. 68 also. This consists of fabric, which has previously been thoroughly washed, being allowed to soak in hot water for at least twelve hours, and then dried. The blades are coated evenly with glue, and the fabric applied and rubbed smooth. After about sixteen hours it is given four coats of paint and two coats of varnish or enamel.

A rigid specification of alignment, track, pitch angles, shape of sections, dimensions of bore and bolt holes in boss is the basis of the final testing, where a quantity of airscrews to a particular design are made.

A final balancing test is also applied and, in order to obtain uniformity in this, and also to ensure that the bearings of the balancing spigot are in good order, it is usual to specify that the apparatus shall be sensitive enough to allow a weight of one ounce, placed in a bolt hole in the boss, to cause the airscrew to turn. One is also usually selected and subjected to a running test for a number of hours at the speed for which it is designed, and afterwards closely inspected for defects such as warp and open joints.

Having satisfactorily passed all tests, the airscrew is stamped on the boss with particulars of

its "pitch" diameter, safe revolutions per minute, right- or left-hand as the case may be, and the maker's name and his identification mark or drawing number.

If it is necessary to store or transport propellers without packing cases, they should always be mounted on a vertical or horizontal spindle passing through the bore. They should be so arranged that no weight is in any way taken by the blades.

CHAPTER VIII

THE COVERING, DOPING, AND VARNISHING OF THE COMPONENTS OF AEROPLANES

THE covering of the components of an aeroplane has been, and is still, the subject of considerable discussion and experiment. Various materials have been used, including calico, silk, goldbeater's skin, paper, cambric, muslin, oiled silk, rubbered fabrics, and aluminium; but the covering materials now universally used are cotton or linen fabrics which are coated with dope and varnish. The use of three-ply wood and metal is restricted to parts such as centre sections and leading edges, which are commonly used as floor boards, footsteps, etc.

The cotton fabrics used are made from Egyptian cotton, the strength being dependent on the weight, which varies proportionally to the warp and weft used.

Warp is the term used to denote the thread which runs lengthwise in the fabric, and

Weft denotes the thread running crosswise. It is usual to buy this fabric in widths of from 36 to 42 in., and in lengths of 50 to 100 yd. The

weight of this should be about 3 to 4 oz. per sq. yd.

Cotton fabrics are not as strong, the weights being the same, as linen fabrics, which are most commonly used. The strength of these fabrics is usually specified by stating the load which would be necessary to break a strip 1 in. in width. Cotton fabrics should be capable of standing up to a load of 80 lb. per in., and linen up to 90 lb. per in. The method of testing samples of fabric requires special care, in order to avoid obtaining misleading results. A considerable number of specimen strips should be cut $2\frac{1}{4}$ in. wide, and of a length suitable to the machine to be used for applying the load.

Half of these should be cut in the direction of the warp, and half along the weft. It is also advisable to see that no two specimens cut in the same direction have the same longitudinal threads, in order that a local variation in the quality of the threads may not have an unduly important effect on the average of the readings. The edges of each piece are then frayed out for a width of $\frac{1}{8}$ in., leaving 2 in. effective width, and these specimens are then soaked thoroughly in water. They are then fixed in the testing machine while still wet, and the load applied at the rate of 300 lb. per minute. Considerable variation will probably be found in individual results; but the average of, say, a dozen specimens should always work out above the specified figures for the minimum strength per inch.

Undoped cotton or linen fabrics deteriorate rapidly when exposed to atmospheric conditions and sunlight, so that it becomes of the utmost importance to ensure that the doping is carried out as soon after the component is covered as possible.

The preparation of the component to be covered consists of painting all the exterior of the wood frame or skeleton plane, with a dope-resisting paint, usually white in colour. This is necessary to prevent the dope, when wet, from penetrating into the surface of the wood and thereby destroying the outer surface. Loss of strength would thus occur, which, although small, becomes important when it is borne in mind that, in order to economise in weight, the designer keeps the rib sections as small as he possibly can. After this coat of paint is perfectly dry, it is usual to cover the outer surfaces of the ribs with cotton tape (*a*) of the same width as the part it covers (see fig. 69). This is done by stretching the tape along the flange of the rib, and securing it with a small copper brad or tack. Liquid glue is then applied and rubbed well in, and when this is dry the tape is firmly fixed to the flange. This tape is used for two reasons, both important ones: the strengthening of the ribs and the provision of a support or buffer for the sewing thread by which the cover is secured. The component—in this case, a "plane"—is now ready for covering. Before this is carried out, however, an inspection of the materials and workmanship of the details used

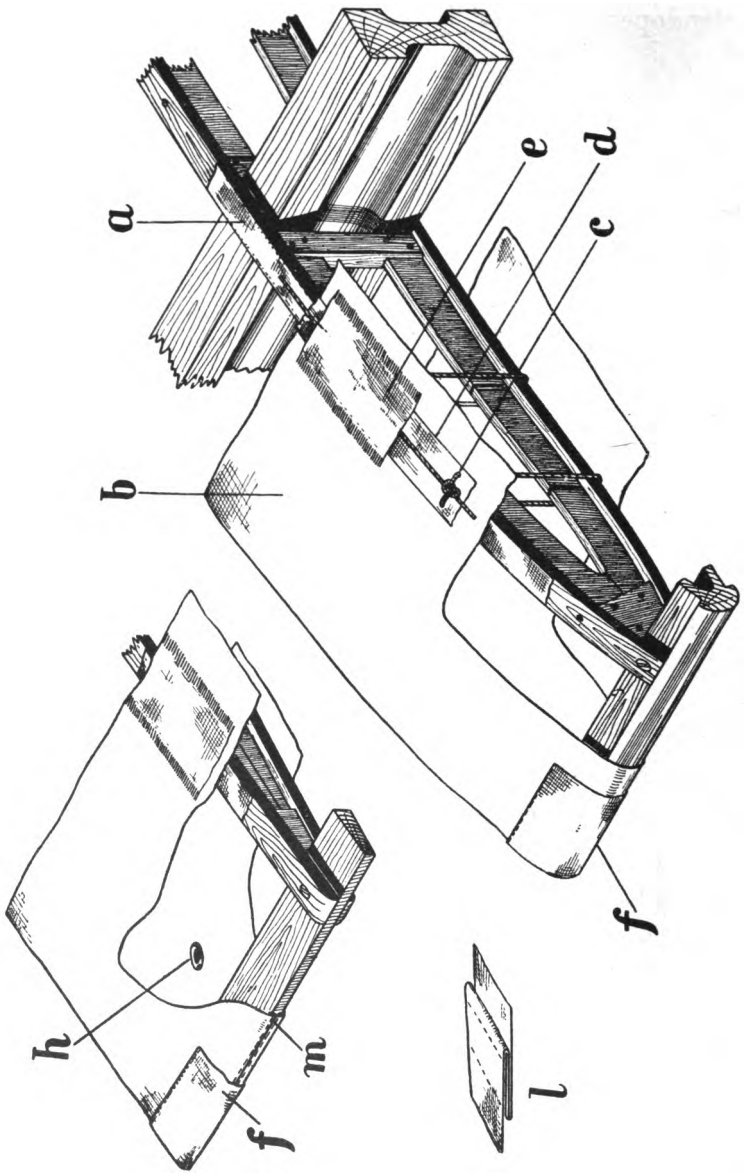


FIG. 69.—Method of covering.

in its construction will prove of value, in the prevention of trouble and expense occasioned by the discovery of mistakes at a later stage, necessitating the opening or total removal of the cover.

The preparing of the cover is the next consideration; this is done by machine-sewing the widths of fabric required together, making the joint by doubling the edges together with an overlap of about $\frac{5}{8}$ in. and double-sewing at each of the laps (see fig. 69, diagram *l*).

The fabric (*b*) is then laid on the plane to be covered on the top surface, passed over the leading edge, and brought to the underneath side. The top and bottom surfaces are then pulled together as tightly as possible round the trailing edge or rear spar in the case of the aileron gap, and hand-sewn with a waxed thread, using the ordinary lockstitch (*m*). Great care should also be taken in stretching the fabric over the frame evenly.

The cover should now be well stretched lengthwise of the plane and sewn around the end rib and tip, also around the rib adjacent to the gap for the aileron, in the same manner as already described. All sewn joints on edges are covered by a protecting strip of fabric (*f*).

It is here necessary to emphasize the need for a perfectly dry fabric when this operation is taking place. It is well known that the action of dampness upon all thread is to contract it. Therefore if the fabric is sewn on when damp, it will expand

again as it dries and become loose and develop wrinkles. This is fatal from the point of view of good workmanship, as no amount of doping will restore the surface to the necessary tautness.

It has become a common practice to provide an additional support for the sewing cord (*c*) by now stretching a tape (*d*) around the cover over the ribs and wherever stitching is required. This tape is commonly known as "Egyptian," and should be at least $\frac{3}{4}$ in. wider than the part which it covers, thereby giving a $\frac{3}{8}$-in. oversail on each side. Having drawn the tape tightly around the ribs, it should be fixed for the moment with pins. The cover must now be fixed to the ribs with small copper or brass brads spaced evenly around the periphery of same, the brads passing successively through "oversail" tape, fabric cover, rib tape, and entering the rib to a depth of approximately $\frac{1}{4}$ in.

The next operation is the sewing of the cover to the ribs. The method of doing this is dependent on the size of the plane. In the case of a small plane having a chord of, say, 6 ft. the best method is to lay the plane on a pair of trestles (see fig. 70 for sewing) and use an upholsterer's needle and No. 1 kite cord. Piercing the cover close to the rib, the needle is then pushed through and should emerge on the under side at a point in a straight line with its point of entry. The needle with cord is then passed over to the opposite side of the rib, and the operation repeated; the needle should

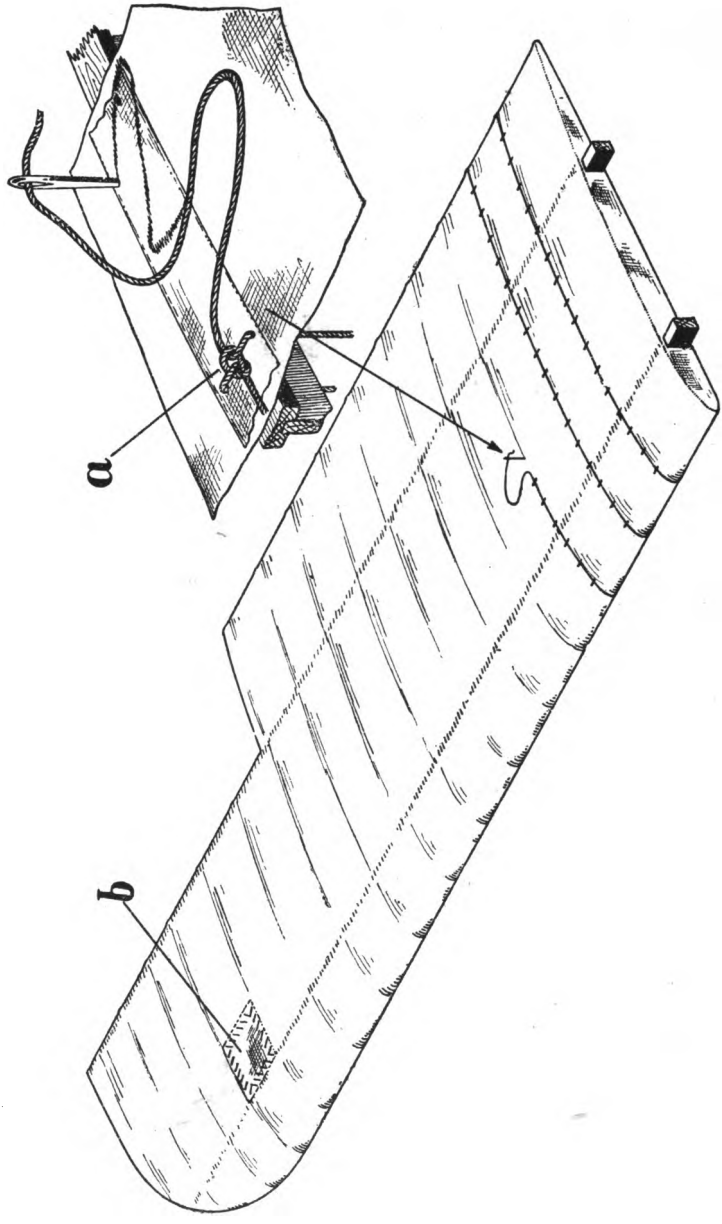


FIG. 70.—Sewing cord over ribs.

emerge on the top side, in a straight line with its entering point. The stitch thus made is now secured by knotting (*a*) (see fig. 70), which should be as near the centre of the rib as possible.

The needle is now passed along the rib and the next stitch made at a distance of about 3 in. from the first one. The distance between the stitches is known as the "stitch pitch," and varies according to the size of the plane. This operation is then repeated along the periphery of all the ribs, with the exception of the end rib, rib adjacent to the aileron gap, and the nose ribs.

The No. 1 kite cord used for sewing the cover to the ribs consist of eight flax threads woven together and should not weigh more than 3 oz. per 100 yd.; it should be capable of supporting a load of at least 33 lb.

It is as well to remind the reader that the suction at the "leading edge" of a plane is very much greater than elsewhere when the plane is in use. This provides sufficient reason for the addition of the nose ribs in the construction of the plane, also for insisting that any joints which may occur in the cover shall not occur at this point.

All bare edges should now be trimmed off, and suitable drainage provided in the cover, for any moisture which may collect. This is done by fixing small eyelets and washers (*h*) made of aluminium or brass similar in shape to those used on the lace-holes of boots. These should, of course, be fixed

after the covering is roughly placed, but previous to it being finally stretched over the frame, and are usually placed in the trailing portion behind the rear spar, on the underneath surface. One between each rib is sufficient (see fig. 69).

The next operation is to place what is known as frayed fabric (*e*) (fig. 69) in position and temporarily fix with pins at the trailing edge and rear spar.

Frayed fabric is made from the same material as the fabric used for the cover, except that when it is being woven, a warp is mixed at the required distance for a width of approximately 1 in. When required for use it is made up into convenient sized rolls by cutting first of all down the centre of the missed warp and then rolling. The edge thus obtained readily adheres to the cover when it is finally doped on.

Where a large plane is being covered the operations are exactly the same as for a small one, with the exception that it is often found to be more convenient to stand the plane vertically on its leading edge and make the stitches in the same manner as shown in fig. 70. By this method a great saving in floor space in the workshop is effected, but the operation becomes two-handed, as it is obviously impossible for the person sewing to walk from one side of the plane to the other at each stitch.

It is often necessary to fit detachable covers (*b*) (fig. 70) for inspection purposes. These are made

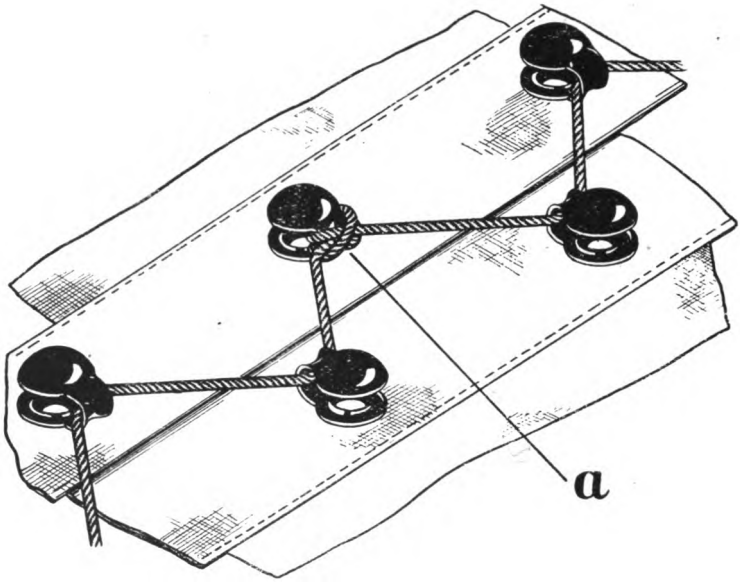


FIG. 71.—Hook fasteners and lacing.

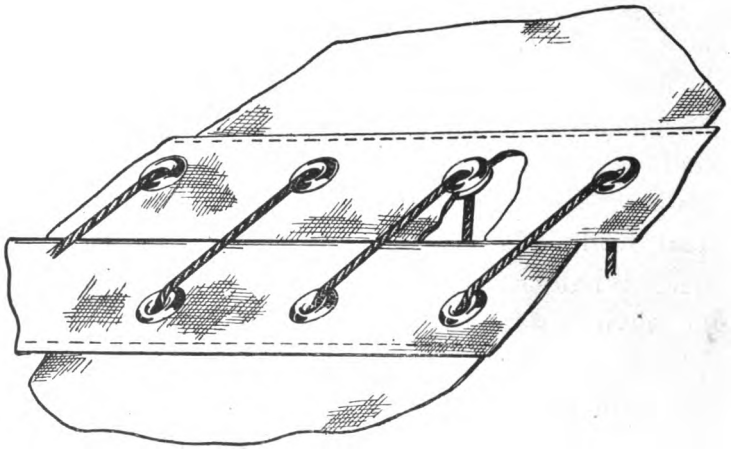


FIG. 72.—Method of edging detachable fabric cover.

with fabric and have their edges stiffened by the addition of a strip of webbing sewn to the fabric as shown in figs. 71 and 72; the edges are then perforated, and the lacing eyelets, usually of brass or aluminium japanned over, are fixed with the "hand punch" shown in fig. 73. The hole cut in the main cover to accommodate such a door has its edges stiffened in a similar manner to that already described, thereby ensuring a perfectly sound joint

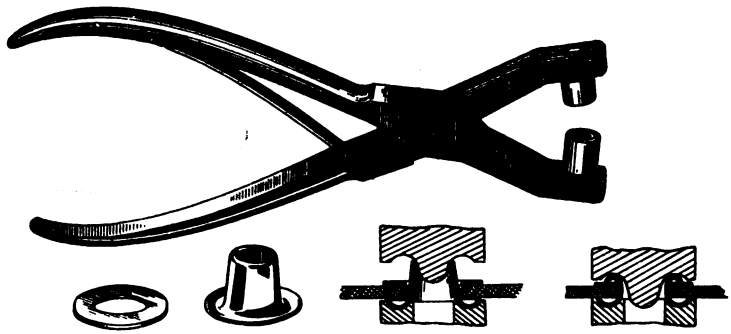


FIG. 73.—Fixing eyelets.

when the cover is laced into position. A knot (*a*) (fig. 71), introduced on, say, every sixth eyelet, is a necessary precaution when using this type of lacing. This prevents the whole of the strip of lacing from coming undone if the cord breaks.

The plane is now ready for doping, and again the procedure varies according to the size of the plane.

It is fairly safe to say, however, that the method most commonly employed is to stand the plane vertically on its leading edge, and, taking about two pints of dope in a small metal can, apply the same

with a good bristle brush, the brush being drawn backward and forward in a line parallel with the ribs, with regular strokes until the surface of the fabric has received a complete coat. The plane is then left to dry; this usually takes from one to two hours, according to the type of dope used and the temperature of the atmosphere in the dope-room, which must be not less than 70° Fahr. and free from direct draughts.

The first coat of dope being dry, the second can now be applied in the same manner as the first. The ultimate tightening effect of the dope being dependent on the first two coats, it is essential that any inspection of doping, which may be considered desirable, should take place at this stage. The operation is repeated for a third and fourth coat, according to the service required of the plane.

The addition of dope to the fabric renders it air-tight, oil- and petrol-proof. A description of the actual composition of dope occurs later in the chapter.

The actual tightening effect is due to the dope being what is known as a "colloid," which does not actually penetrate the fabric when applied, but merely fills the interstices on the side of the fabric coated. When the solvent evaporates, the globules remaining contract in the direction of the plane of the fabric.

It is also possible to spray this dope on to the plane by means of an aerograph spray painter. In

using this device the dope is emptied into a special container which is connected to the compressed air service, which is an auxiliary fitted to every up-to-date works nowadays. The air pressure forces the dope along the flexible pipe to the actual sprayer, which the operator holds in his hand. The amount leaving the sprayer is controlled by a needle valve which is moved by a trigger. This is a particularly neat and rapid way for applying dope, but it should not be used for the first coat. It has already been explained that the proper action of the dope depends upon it filling the minute spaces between the threads composing the warp and the weft. The spraying does not accomplish this, it being necessary to thoroughly brush this first coat in with a good bristle brush. It should be possible to overcome this objection by carrying out the operation in an enclosed chamber under a small air pressure which tends to force the dope into the spaces and also to eliminate the chances of air bubbles forming. This system has been used experimentally, and there does not appear to be any insuperable difficulty in adapting it to ordinary commercial practice.

The room in which dope is applied must be fitted with suction fans at floor level in order to discharge the slightly poisonous vapours given off into the open air. The fumes, being heavier than air, always sink towards the floor. The importance of this provision, therefore, must not be overlooked, as is also the case with a continuous supply of warm air

which is essential in order to carry out the drying as rapidly as possible. The effect of properly executed doping upon the weight of the fabric is to increase it by about 35 to 45 per cent. per sq. yd., while its strength is increased by about 20 per cent.

A single gallon of dope should be sufficient to cover 6 sq. yd. of fabric with four coats. This varies according to the conditions, of course, but is a sound basis for calculating consumption.

Most dopes are cellulose nitrate or acetone solutions, the commonest used being a solution of cellulose acetate in acetone, methyl alcohol, or tetrachlorethane; the use of the last, however, should be avoided if possible on account of its extremely poisonous effects upon the human system. The actual formula for a typical dope is as follows :—

Acetyl cellulose . .	7·5	per cent.	weight.
Triphenyl phosphate .	1·0	,,	,,
Benzyl alcohol . .	3·0	,,	,,
Acetone . . .	88·5	,,	,,

Dope is usually supplied in metal cans, and the label attached to the same should give full particulars of weight and date of manufacture. The acetyl cellulose is the "colloidal" material which fills the pores of the fabric, while the triphenyl phosphate mixed with it gives the necessary protection against the atmosphere. The softening agent is benzyl alcohol, which renders the film of dry dope flexible. The acetone dissolves the other ingredients,

and reduces them to the fluid state in order that they may be applied. The drying operation evaporates this, leaving the dry film composed of the other items only. The brushes for applying the dope should be at least 3 in. wide, and consist of the best hair, bound to a wooden handle with a metal ferrule.

It is obvious that the principal requirement of a dope can is the prevention of evaporation. An

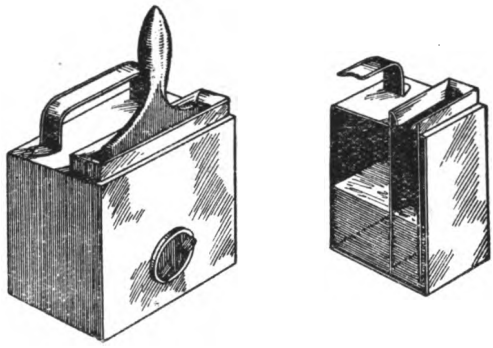


FIG. 74.—Dope can.

excellent form of this is shown in fig. 74. Needless to say, this type does not completely overcome evaporation, but is nevertheless a handy and economical one. Containers for dope must always be kept tightly corked when full, not only to prevent evaporation, but also deterioration.

Finishing Material: Varnish. — After the last coat of dope is dry, in order to give the plane a finished appearance and also a general protection against dampness, washing down, oil splashes, etc., it is usual to add two coats of finishing materials,

which consist of a varnish, either a clear spirit or oil varnish.

The spirit varnishes consist of a dissolved resin with alcohol, methylated spirits, etc., as the solvents.

The oil varnish is usually composed of thickened linseed oil and turpentine, with the admixture of a small quantity of resin.

The actual application is made in a manner similar to that described for the application of dope.

The following is a summary of the principal requirements for good covering and doping, etc. :—

(1) The fabric must be pulled tight.

(2) The fabric must be dry.

(3) The dope should be applied in a well-ventilated room at a temperature of not less than 70° Fahr.

(4) The first coat should be applied evenly.

(5) Use a stiff flat brush, quite full.

(6) The remaining coats should be laid on carefully and evenly. It should not be "worked," *i.e.* when applying the dope do not rub the brush across the line of the stroke first made, as this is liable to produce small bubbles, which diminish the weathering properties of the doped fabric. Also avoid thick patches.

(7) Each coat must dry thoroughly before application of the succeeding coat.

(8) Under no circumstances should thinning be used with dope.

(9) At the finish of the day's work, the brushes should be placed in a can filled with a prepared brush wash, having acetone as its chief ingredient.

Aluminium dope has recently become more popular. It consists of a dope made more or less on the lines of that already described, with the admixture of an aluminium powder at the rate of ½ lb. per gallon. Great care should be taken to ensure that this dope is well stirred before application, as the aluminium will tend to sink to the bottom of the container.

Its application is precisely the same as for ordinary dopes, but a finishing varnish is not required. This may ultimately prove the chief reason for its adoption, as the doing away with the necessity for the application of several coats of varnish is obviously a great saving, both in time and cost of production.

CHAPTER IX

INSPECTION OF AIRCRAFT PARTS

THE detail inspection of parts during manufacture, which is now accepted as desirable in all engineering work, becomes essential when dealing with aircraft parts which are often highly stressed and subject to severe shocks, while the safety factor is reduced to a minimum in order to save weight as far as possible.

This is especially the case when dealing with such parts as landing gears, main spars, lift wire fittings, etc. Inspection during and after machining is especially necessary, for it is most important that parts which are weak or faulty shall be discovered before they reach the erecting shop. It is often impossible to discover tool-cuts, flaws, or errors in workmanship when the parts are assembled; and even if discovered, it often means pulling a unit to pieces to replace the defective parts.

To ensure interchangeability of parts, and also that all units shall assemble correctly, it is necessary to fix limits for the various jigs and gauges which, while allowing the machine shop as large a tolerance as possible on unimportant dimensions, will ensure

that the important dimensions are within the drawing limits.

The inspection of raw material is usually carried out at the maker's works, or on arrival in the stores. Each batch of steel sheet, tubes, or bars, should be marked, as a means of identification (in case of any material proving defective). This is usually done by painting the different specifications different colours. Samples of each batch of material should be taken for tensile and impact tests, to see that the material is up to the specification.

A very convenient method of checking the tensile strength of a suspected bar (where a tensile testing machine is not available) is by means of the "Brinell hardness test," which also provides a simple method of testing high-tensile steels after heat treatment, to see that they are up to the required hardness.

This test is not intended to be used on hardened parts, which can be tested by the Shore scleroscope method. This consists of dropping a diamond-faced hammer from a fixed height on to the sample to be tested, and comparing the rebound with the rebound from a standard test piece.

Further reference is made to the Brinell method of testing later in the chapter.

Before dealing with the actual inspection of metal fittings and parts, a short description of some of the tools and equipment used in the inspection department may be of interest.

Nearly all the accurate measurements on external

cylindrical work are made by means of the engineer's micrometer, illustrated in fig. 75. This tool is too well known nowadays to need an elaborate description.

The spindle has forty threads per in., each having ·025-in. pitch; therefore $\frac{1}{25}$ of a revolution will advance the spindle $\frac{1}{25}$ of ·025 in., *i.e.* ·001 in. or $\frac{1}{1000}$ of an in. The thimble having twenty-five divisions on its circumference, a movement of one division is consequently equal to $\frac{1}{1000}$ of an in.

On the right-hand side of fig. 75 a micrometer is shown held in a stand, which is often used when making careful measurements. This illustration also shows the micrometer fitted with an appliance which is sometimes used to convert it into a temporary limit gauge. The "mykarms," as they are called, are clamped on the thimble in such a position that the spindle can only make a part of a revolution in either direction. One arm is set to stop the rotation at the low limit, and the other at the high limit. It will be noticed that these fittings cannot be used for a limit that demands more than, say, seven-eighths of a revolution of the thimble, but with this limitation these arms form an extremely useful addition to a micrometer.

Another very necessary tool is the "Vernier sliding calliper gauge," illustrated in fig. 76; the knife-edge jaws at the back (as shown at (*a*) in the illustration) are very useful for measuring the thickness of steel tubes, the diameters of under cuts

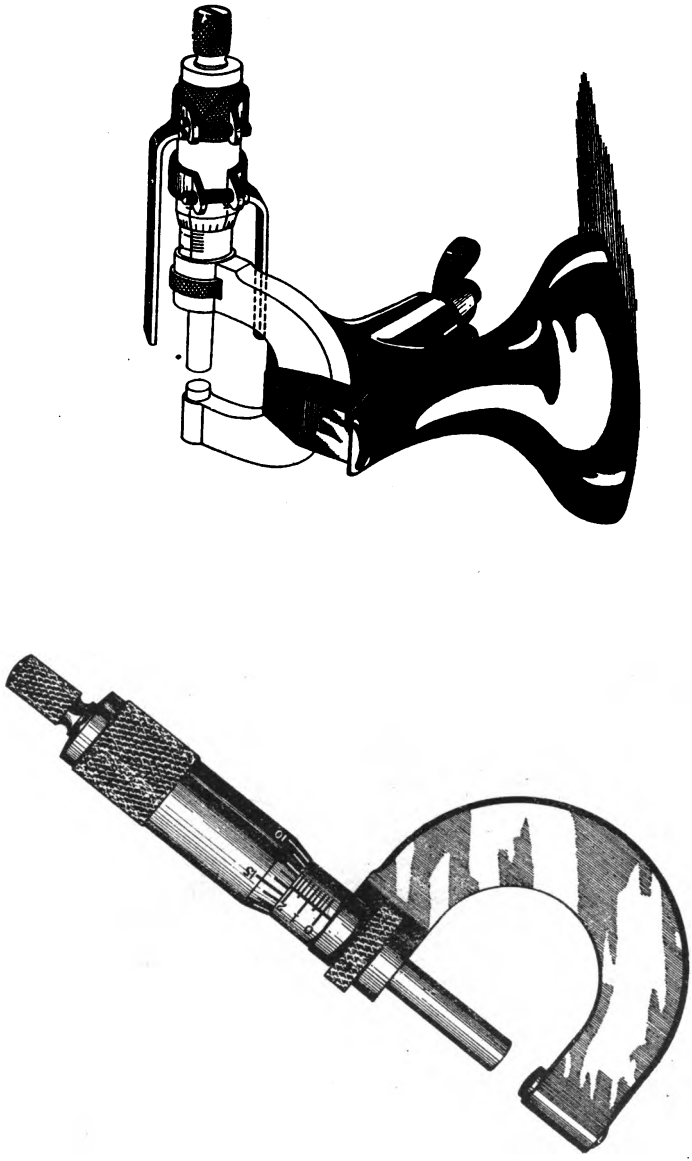


FIG. 75.—Micrometer "mykarms" and bench stand.

at the back of screw threads, the core diameters of threads, the pitch of holes, and also for measuring the thickness of metal around the pin holes, in wiring plates, lift wire lugs, etc.

This tool can be used for measuring internal diameters at the end of the jaws (marked (*c*) in

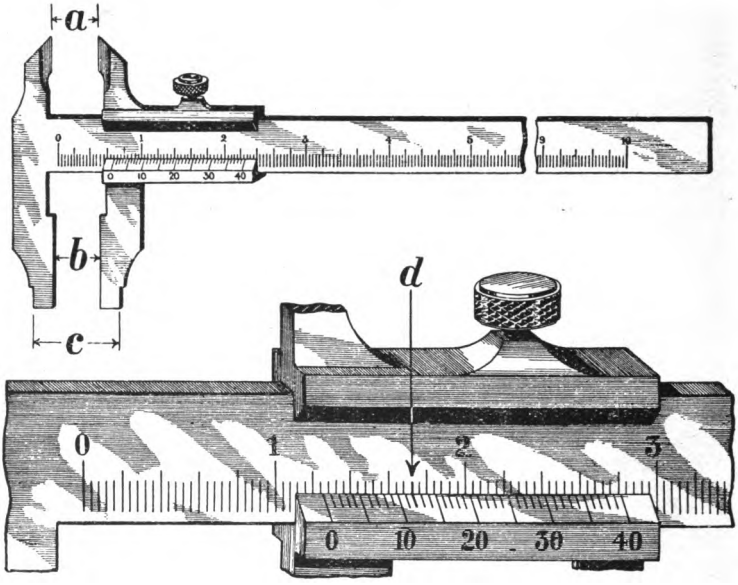


FIG. 76.—Roche vernier callipers.

fig. 76). These ends are finished to a given size, ·4 in. in the tool illustrated, which is added to the reading on the scale.

The gauge illustrated is known as a Roche vernier calliper, and is graduated to read to ·001 in. by means of the vernier scale, shown enlarged at the bottom of the figure.

The large divisions on the beam are ·040 in.

apart; the sliding jaw has forty divisions, which cover thirty-nine divisions on the beam: therefore the lines on the vernier scale are ·039 in. apart. Consider the gauge closed with the faces (*b*) in contact and with the scales at zero; a movement of ·001 in. will bring the second line of the vernier in line with the second line on the beam, and every further movement of ·001 in. will bring one line further down the vernier scale in line with a mark on the beam. When the last line on the scale coincides with a line on the beam, the zero line will also agree with the second line on the beam, and the gauge is open ·04 in. After this any reading on the beam, to the left of the zero line of the vernier, must be added to the vernier scale reading. To consider an example, first read the measurement to the left of the vernier scale; then look along the scale until the line is found which agrees with a line on the beam; then add the number of lines to the left of this to the measurement on the beam. The reading in the enlarged view at the bottom of the figure is 1·252 in. (*i.e.* 1·24 on the beam + ·012 on the scale, for it is the twelfth line (*d*) on the slider that coincides with a line on the beam).

Another tool, used for the measurement of angles, is the protractor illustrated in fig. 77, which may be graduated to read in degrees only, or to read to five minutes by means of a vernier, as drawn.

Another and a cheaper type of protractor is shown in fig. 78.

For testing the bore of sockets, the diameters of

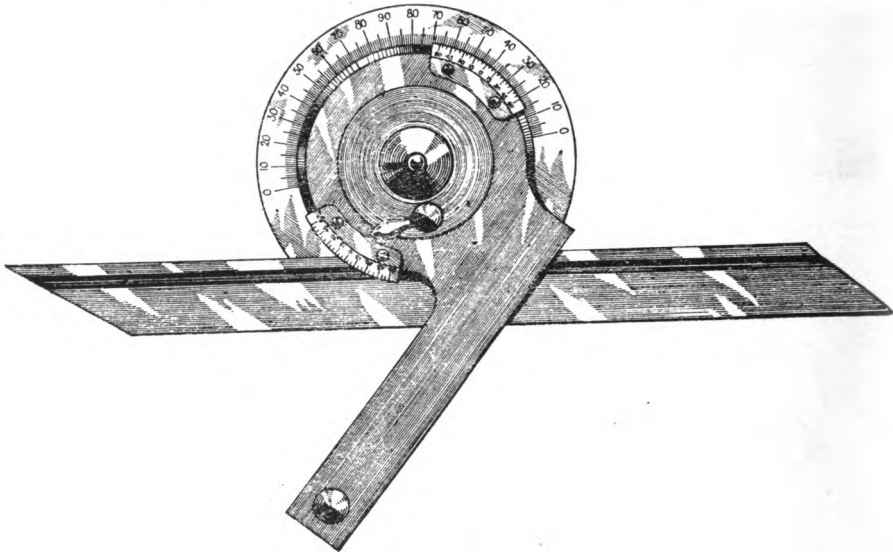


FIG. 77.—Universal bevel protractor with vernier.

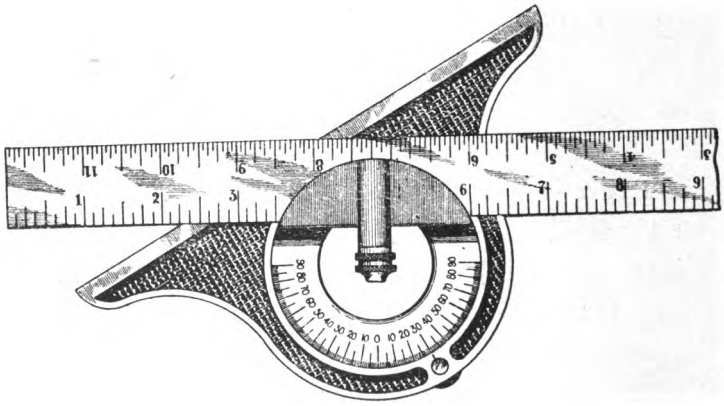


FIG. 78.—Bevel protractor.

holes in fittings, etc., a set of plug gauges will be required. These are usually of the pattern

shown in fig. 79, the "go" end being made to the bottom limit, and the "not go" end to the top limit.

Screw threads are usually tested by means of a standard screw gauge, such as the one shown in fig. 79, or by means of a thread micrometer.

The use of the shadow projection apparatus is

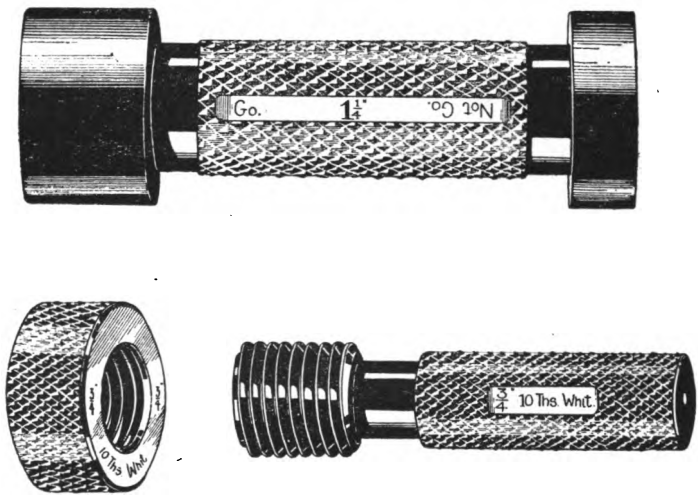


FIG. 79.—Plug gauge and screw gauge.

usually confined to test pieces from new dies, screw gauges, and taps. In this method a section of the thread under test is placed in a beam of light which passes through a suitable lens and projects a magnified shadow or outline of the profile of the thread on to a screen; the magnification usually used is 50 diameters.

The correctness of the formation, pitch, and angle of the thread is then checked by allowing the

shadow to fall on a carefully drawn outline of the thread, which is placed on the screen.

A very convenient tool for measuring the thickness of the crowns of sockets, or of a casting behind a shoulder, is shown in fig. 80. The sketch gives a

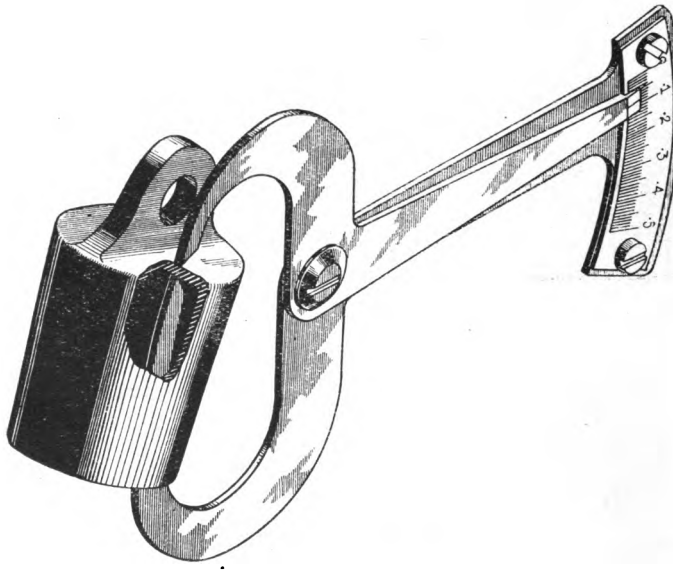


Fig. 80.—Indicating callipers.

good idea of the use to which the indicating callipers may be put.

In addition to the above, a variety of engineers' small tools are used, such as callipers, height and depth gauges, parallel strips, thread pitch gauges, etc.

In complicated parts with a number of faces at different angles it is often necessary to mark out one or more of the parts after machining, to see

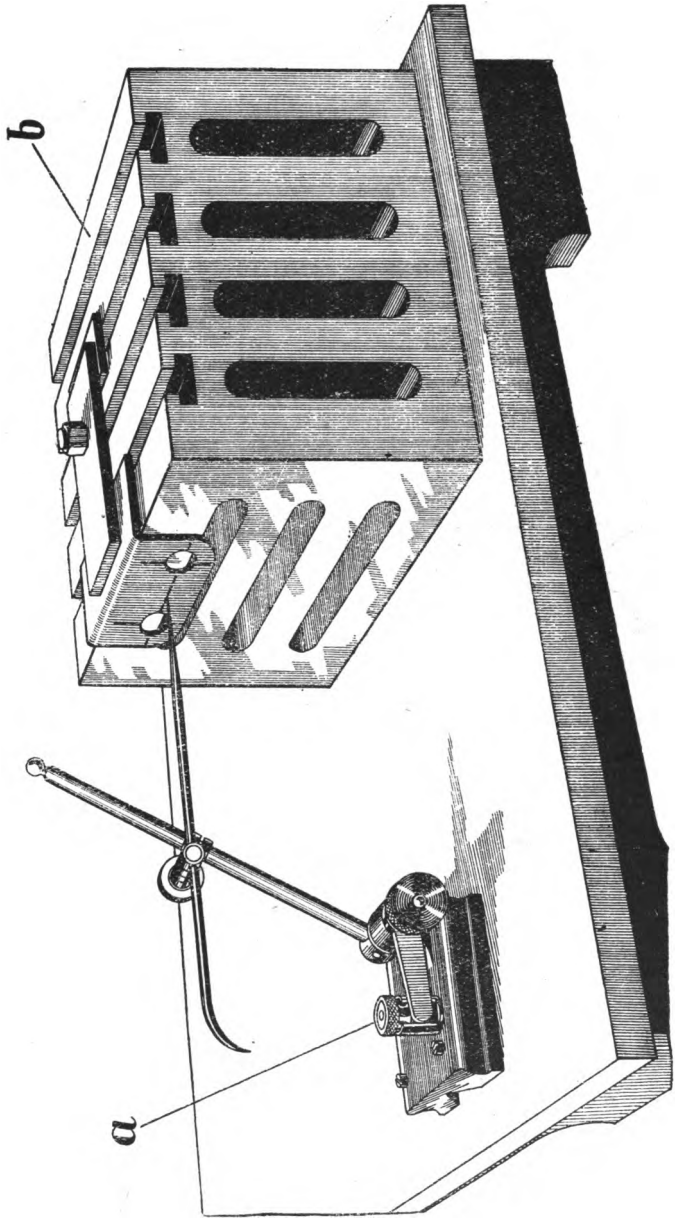


FIG. 81.—Surface plate, box jig and scribing block.

that the various faces and angles are correct. A surface plate as shown in fig. 81 is often used for work of this kind, in conjunction with a "box jig" such as (*b*) to which the fitting to be marked out is clamped.

The advantage of this box form of angle plate

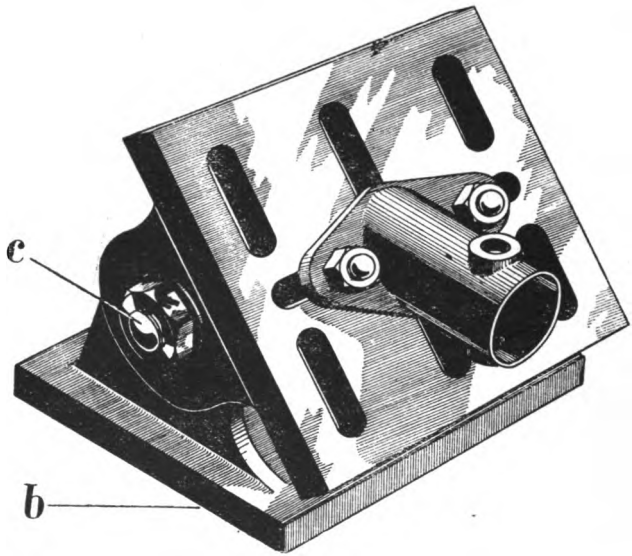


FIG. 82.—Adjustable angle plate.

is that it can be tipped on to any one of its faces, to test surfaces at 90° to one another, while by packing up one end a job can be tilted to any angle required. The slots in the top and sides provide an easy means of fixing the work to the box jig.

Fig. 82 shows an adjustable angle plate which is also used on the marking-off slab. The work is

bolted (or clamped) on to the top portion as shown. This top plate is hinged on the base (*b*) by the two bolts (*c*), so that the top can be turned through any angle, and locked in the required position by tightening the nuts on the bolts (*c*).

The actual marking or lining off is done by a steel scriber, held in a scribing block, such as the one illustrated in fig. 81. The milled screw (*a*) is to obtain a fine adjustment after the scriber has been locked in approximately the correct position.

The tools just described are a few of those in general use in the view room. In addition to these, a number of special jigs and templates are usually made, for rapidly checking any fittings which are made in large quantities, or where a number of holes have to be located accurately in relation to one another.

As stated previously, it is very desirable to fix on a definite system of limits or tolerances for the various parts, for the reason that, commercially, it is not possible to produce a number of parts all exactly the same size.

For aeroplane fittings the following limits have been found to give satisfactory results in practice, and they are generally accepted as sufficiently accurate for the purposes stated.

Holes that are to take well-fitting pins or shafts are reamered to the "Newall standard" B fit limits. Those which do not require a perfect fit are made to a limit of +·005 in., −·000 in.

Clearance holes are usually drilled to +·015 in., −·000 in.

Pins and shafts, where accurate fits are required, are usually produced to the Newall system of limits, the D, P, and X or Y fits being used for driving, push, or running fits, respectively.

Sockets or lugs are usually bored to a limit of +·005 in., +·010 in. if tubes are to be sweated or brazed into them. For gauging work to these limits a set of + plugs are usually used. In this case both ends of the plug are over the standard size—for instance, a 1-in. plug is 1·005 in. at the "go" end and 1·010 at the "not go" end.

Tubes.—The following errors are usually allowed in steel tubes over $\frac{3}{8}$ in. diameter :—

Errors in Straightness. — Ordinary tubes not to exceed $\frac{1}{600}$ of their length, or ·02 in. per ft.

Axle tubes not to exceed $\frac{1}{300}$ of their length, or ·04 in. per ft. of length.

Errors in Thickness.—Tubes under ·06 in. in thickness, ±·004 in. When thicker than ·06 in., $7\frac{1}{2}$ per cent. of their thickness.

Variation from nominal not to exceed +15 per cent. or −10 per cent. at any one point. Axle tube may be +20 per cent.

Diameter Tolerance.—Under 2 in. diameter, ±·004 in., over 2 in. diameter $\frac{\text{diameter}}{500}$.

22 S.W.G. tubes are made ·025 in. thick,

with a tolerance of +·004 in. Axle tubes may be ±·005 in.

Steel sheets for making fittings should be within the following limits :—

Sheets	6 to 13 S.W.G. .	. +·008 in. or −·006 in.
,,	14 ,, 18 ,, .	. +·006 in. or − 004 in.
,,	19 ,, 22 ,, .	. ±·003 in.
,,	23 S.W.G. or thinner	. ± 002 in.

Errors in Angular Measurements.—It is always a matter of difficulty to fix any general limit for errors in the angles of lugs and other fittings, for in many cases very little error is permissible, while in other cases an error of 1° either way is not of great importance.

It is general practice to allow a limit of $\pm\frac{1}{2}°$ unless the job calls for special accuracy, in which case the permissible error should be stated on the drawing.

Screw Threads.—The question of fixing standard limits for the production of screw threads, taps, and screw gauges has received a great deal of attention during the last few years, especially by the Engineering Standards Committee and the National Physical Laboratory, whose investigations into the permissible errors on outside, effective, and core diameters, angle of thread and pitch errors, have been published in special reports issued by the Committee, to which the reader is referred for full particulars of the limits for different classes of work, should he be particularly interested in this branch of the work.

It will now be convenient to consider some of the methods used in the inspection of various parts of an aeroplane, and it is hoped that these brief descriptions will be of some assistance to the reader, if only by indicating where faults are most likely to occur.

All castings should be examined for flaws, blow holes, and spongy places. Aluminium and brass castings that have to carry oil or petrol should be tested under pressure both before and after machining.

A convenient method of testing is by means of air pressure, which will usually show up any leaks that are likely to cause trouble at the low pressures used in the petrol and oil systems.

Where there is a compressed air main near, a branch can be taken off it, with a pressure gauge to show the pressure on the casting under test. If there is no compressed air available, a simple apparatus, such as that illustrated in fig. 83, will answer quite well for pressures up to 25 lb. per sq. in.

The air receiver is provided with a nipple (*n*) to enable connection to be made to the job (*d*) under test, by means of the flexible pipe (*e*), which, after all the openings have been sealed by plugs, or by a clamp and rubber pads (*c*), is connected to the air receiver (*a*) or to the compressed air main. The air pressure is applied by means of the pump (*b*). The casting (*d*) under test is then immersed in a

tank of water, as shown on the right, and any leaks can be seen by the escaping bubbles of air.

Petrol system fittings should be sound under a pressure of not less than 10 lb. per sq. in.

Oil system fittings should be tested to 20 per cent. over the pressure they are to be subjected to in use.

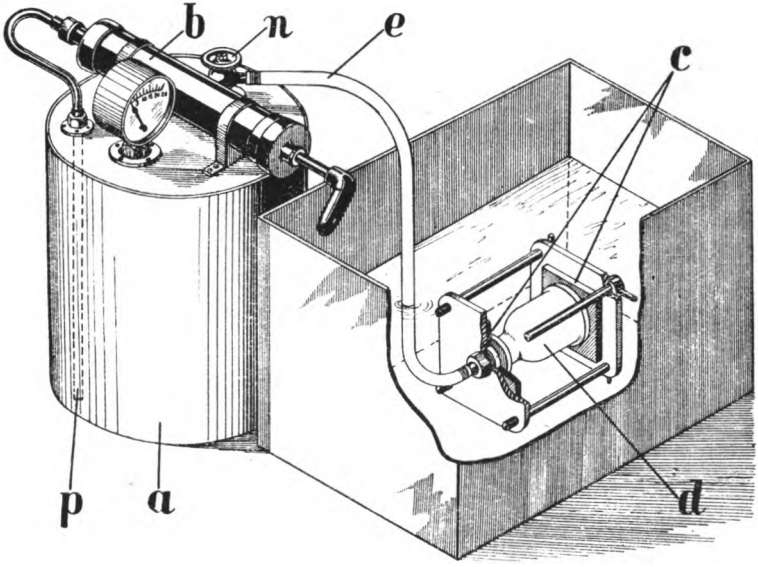


FIG. 83.—Apparatus for testing castings under air pressure.

By filling the air receiver illustrated half full of petrol it can be used for testing petrol cocks with petrol under pressure, the compressed air forcing the petrol up the pipe (*p*) and so on to the article under test.

Dealing with the examination of sheet metal fittings, when parts are built up of sheet steel, aluminium, or one of its many alloys, special care

should be taken to see that the metal is not cracked at the corners in bending, or overheated and burnt in welding. Any sign of burning or weakening of the plate will usually be found at the junction of the plate and the weld. Wherever possible the welding should form a fillet, or radius, in the angle of the fitting. Welded joints should also be examined to see that the metal has been heated sufficiently to make a homogeneous joint.

After welding all sheet steel fittings should be normalised by placing them in a covered steel tray and heating them to a temperature of 850° Cent., after which they should be allowed to cool slowly; this removes any stress or brittleness due to the bending or welding operations.

It should be part of an inspector's duty to see that this operation is carried out, and also that it is performed properly. It is usual to have some special form of stamp on each fitting to indicate that it has been normalised, or else not to put on any inspector's mark at all until this operation is finished. This precaution is very necessary, as after the fittings are enamelled or painted it is impossible to tell from their appearance that the normalising has been missed.

To illustrate the use of the surface plate and scribing block in inspecting a few fittings, where a gauge or templates are not available, a simple fitting is shown in figs. 84 and 85 set up on the box jig.

Fig. 84 shows the method of checking the socket

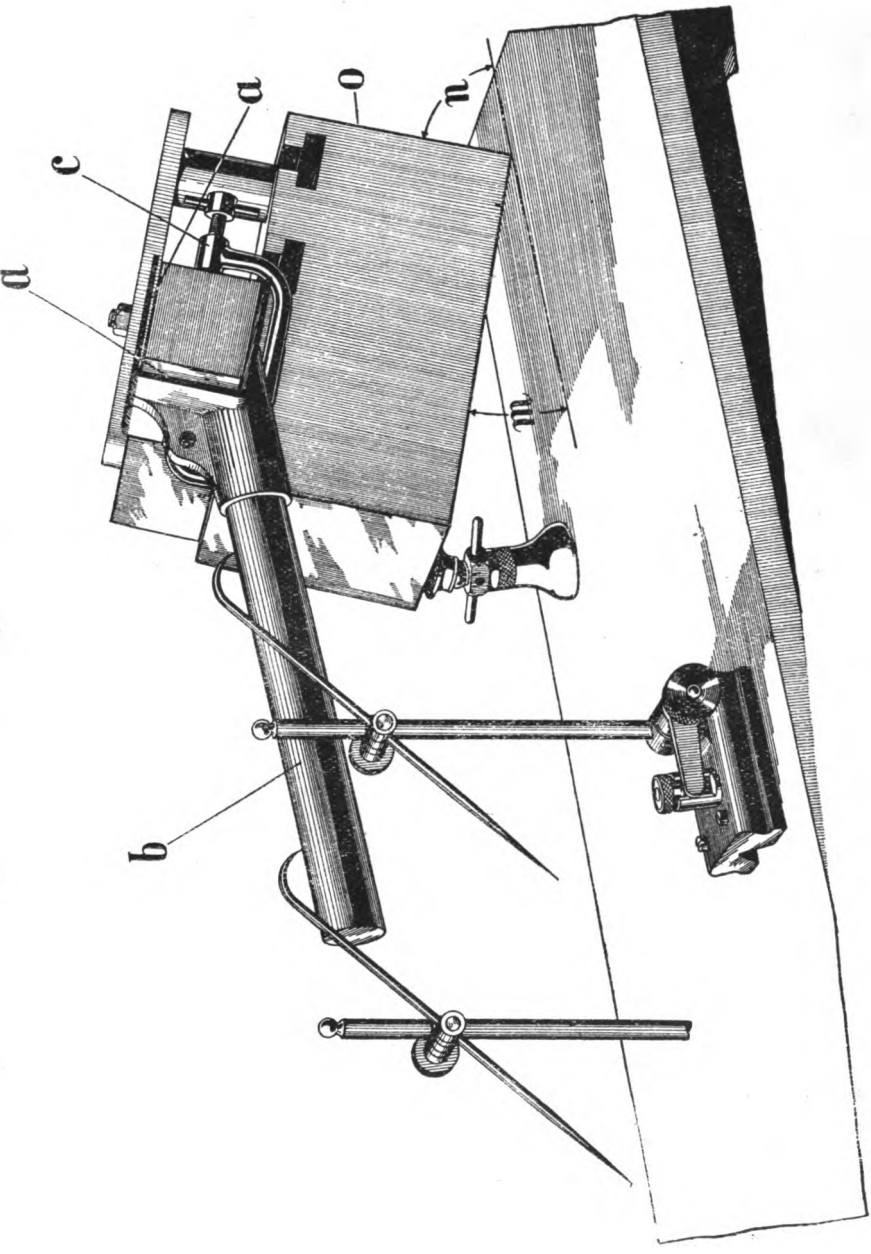


FIG. 84.—Box jig tipped to test angle of socket.

(*s*) (see fig. 85), in order to ensure that it is welded on to the fitting at the correct angle, which should be 20° in the example taken.

A parallel strip of iron or steel is fixed firmly to the box jig by means of the plate and bolt as shown, care being taken to see that it is square and true. The fitting is then mounted on the projecting end of the parallel strip, and held in position by means of the clamp (*c*), taking care that the faces (*a*) (a_1) are true with the face of the steel strip.

The easiest way to check the angle of the socket, which is now pointing downward, is by fitting a parallel steel test bar (*b*) into the socket, and raising the end of the box jig until the test bar is parallel with the surface plate. This can be tested by the scribing block, as illustrated. The angle (*m*) is then measured by a protractor, such as the one illustrated in fig. 77, and if this angle is 20° the socket is correct. If more convenient, the angle (*n*) may be measured instead of (*m*), and this angle subtracted from 90° will give the angle required.

The box jig is now tipped on to the face (*o*) (see fig. 85) to check the positions of the bolt holes (*a*), (a_1), (a_2), etc. The scriber is set level with the top of the parallel strip (*e*), and a rule (*r*) is mounted in a stand and moved until one of the 1-in. lines is level with the point of the scriber.

The scriber is then moved downward ·7 in., and a line is marked across the face of the fitting at ($a\,a_1$). If this line passes through the centre of the

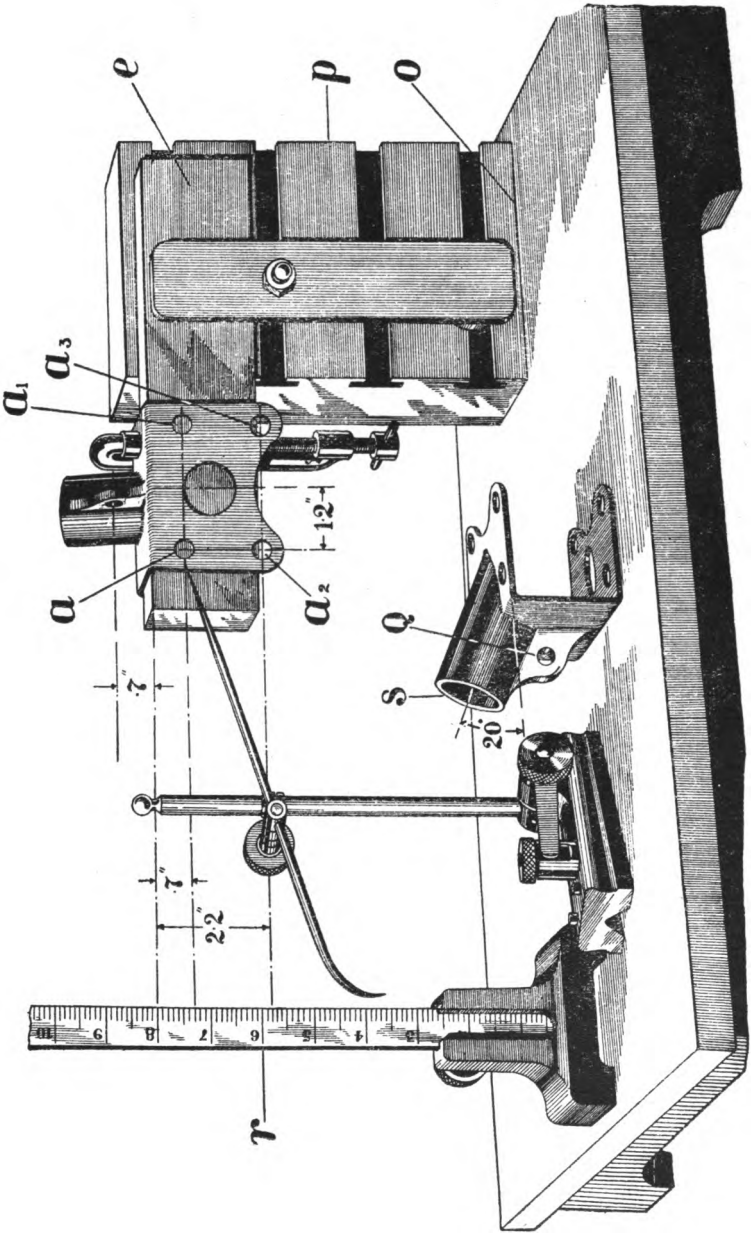


FIG. 85.—Box jig in position to mark off distance of holes.

holes, their vertical position is correct. The scriber is then moved down to 2·2 in. from the top, and another line is marked across the fitting at (a_2 a_3) to check the position of the bottom holes. The position of the corresponding holes on the other side of the fitting is checked with the same setting of the scriber as the front holes, the position of the hole in the lug (q) is also marked off ·7 in. above the top of the parallel strip. The box jig is then tipped on to the face (p), to mark off the position of the holes at right angles to the line (a a_1). First mark the centre line through the large lightening hole, and then mark off the positions of the holes 1·2 in. above and below this line.

The fitting may now be taken off the block, and the length and width measured. The diameter of the hole in the socket is measured with a limit plug (see fig. 79), also the diameter of the bolt holes, and the hole for the bracing wire fitting, in the lug (q). The thickness of metal around this hole should also be measured, the knife-edge jaws on the gauge illustrated in fig. 76 being used for this. The bends and welds should be examined for flaws or cracks, and the thickness of the metal measured, to see that it is of the correct gauge.

This method of inspection, by marking off fittings, is only used where a small number of parts, or the first of a batch, have to be examined. When large numbers are to be inspected, a gauge is made so

that the position of the holes, width of fitting, and angle of socket, can be checked without marking off.

Tubes used for frames, landing gears, axles, etc., should be examined for flaws, seams, and dents. They should also be tested for straightness, by rolling them on a surface table, or by revolving them on a pair of Vee blocks.

In examining the woodwork of a machine, especial care should be taken in checking the main spars and the longitudinal members of the frame. These should first be examined to see that the bolt holes, etc., are in the correct positions, and measured to see that they are correct to the drawing dimensions, after which they should be carefully examined to see that there are not any places where the grain runs across instead of in the direction of the spar.

Ribs are usually built up in a jig. It is then only necessary to see that the joints are well made, and that the wood is not split by the screws, or brads.

Where struts or frame members fit into sockets it is important to make sure that the wood beds down to the bottom of the socket, so as to relieve the bolts of any load due to the compression of the strut. These points are more fully discussed in the chapter dealing with the manufacture of these parts.

Reference was made to the Brinell method of testing steel previously. This method has come into extensive use during the last ten years, and, although strictly speaking it is a hardness test, it is used as a means of estimating the tensile strength

of steels, for a close relation exists between the hardness of steel and its ultimate strength.

Briefly the Brinell method consists of partly forcing a hardened steel ball into the sample to be tested, so as to make a spherical impression. The diameter of this impression is measured by a microscope, and the spherical area is calculated. The pressure used in kilograms is divided by the area of the impression in sq. mm., and the quotient is termed the hardness numeral.

A standard type of machine is illustrated in fig. 86; a ball, 10 mm. diameter, with a pressure of 3000 kilograms, is used in the ordinary test. If necessary a pressure of 500, 1000, or 2000 kilograms can be used by removing the weights, some of which are shown removed in the illustration.

When using a lower pressure the hardness numeral is proportional to the pressure used. The coefficient by which the hardness numeral must be multiplied to estimate the tensile strength of the sample tested may be determined by test, and is constant for any one class of material.

The following coefficients are given for different grades of steel:—

For	Tensile strength in kilograms per sq. mm.	Tensile strength in tons per sq. in.
Hard steel .	Hardness numeral × ·350	Hardness numeral × ·222
Medium steel	Hardness numeral × ·355	Hardness numeral × ·225
Soft steel .	Hardness numeral × ·360	Hardness numeral × ·228

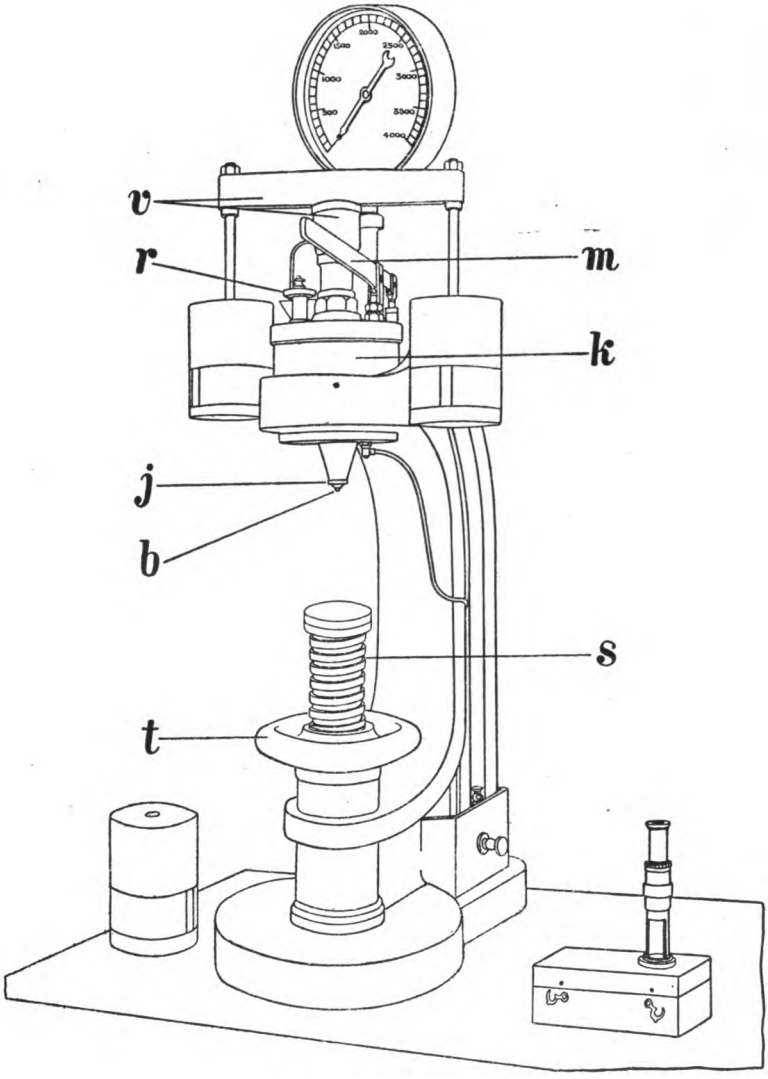


FIG. 86.—Brinell testing machine.

The hardness numerals are usually obtained direct from tables supplied with the machine, without calculation.

In the machine illustrated in fig. 86 the steel ball (*b*) is carried at the end of the ram (*j*), which is forced downward by means of a piston in the oil cylinder, the pressure being applied by the hand pump (*m*). The piece to be tested is placed on the head of the large screw (*s*), which is raised by the hand wheel (*t*) until the test piece touches the ball (*b*); the pressure is then applied by a few strokes of the hand pump; when the correct pressure is reached, the weighted relief valve (*v*) is lifted by the oil pressure which serves to keep the pressure constant during the test.

The pressure should be maintained for about fifteen seconds. It is then released by the by-pass screw (*r*), and the diameter of the impression is measured by a special microscope supplied with the machine, shown on the right of the illustration. The hardness numeral for the diameter in question is obtained from a table, and this number multiplied by the coefficient for the material under test gives the approximate tensile strength.

CHAPTER X

ERECTING AND RIGGING AN AEROPLANE

AN aeroplane being practically a power-driven kite capable of longitudinal and lateral control, which control is exerted by the action of certain of the surfaces, with due regard to their position relative to the centre of gravity of the whole machine, it follows that the erection and rigging of the various members forming these parts is a matter requiring considerable care and attention.

Before a person can become a first-class rigger, capable of assembling a completely dismantled machine correctly, in accordance with the designer's intentions, and in order that he may have an intelligent interest in the job, he must first of all at least acquaint himself with the various terms commonly used and their meanings. These are explained at length later. It is not suggested that a man, in order to be able to assist or even completely rig a machine, should take a long course of instruction on the subject, but rather that it will undoubtedly tend to the elimination of mistakes if the first laws of the construction are appreciated.

Under the heading of rigging may be included every operation in the erection of the finished components, with the exception of the fixing and tuning-up of the engine or engines.

The order of carrying out these operations will vary to a certain extent with the design of the machine, and also with the particular requirements of the shop; but as a general rule the following will be the procedure.

Figs. 87 and 88 show a typical modern fast single-seater tractor machine fitted with an air-cooled radial engine, which will serve as a good example upon which to base this description. Assuming that the fuselage has been fully erected, as previously described, with all internal fittings added as far as practicable, the sequence of operations will now be as follows:—

(1) Fix the undercarriage (*a*) in position, and true it up with its cross bracing wires (*b*).

(2) Place the engine (*c*) and radiator, if any, in position, and secure them.

(3) Fix the tail planes (*d*), elevators (*e*), rudders (*g*), and fins (*f*).

(4) True up these, using their bracing wires.

(5) Place the top centre plane (*h*) in position on its struts, and true up approximately.

(6) Place the bottom planes (*j*) in position.

(7) Brace up by placing the first landing wires (*k*) in position between the top centre and the bottom plane.

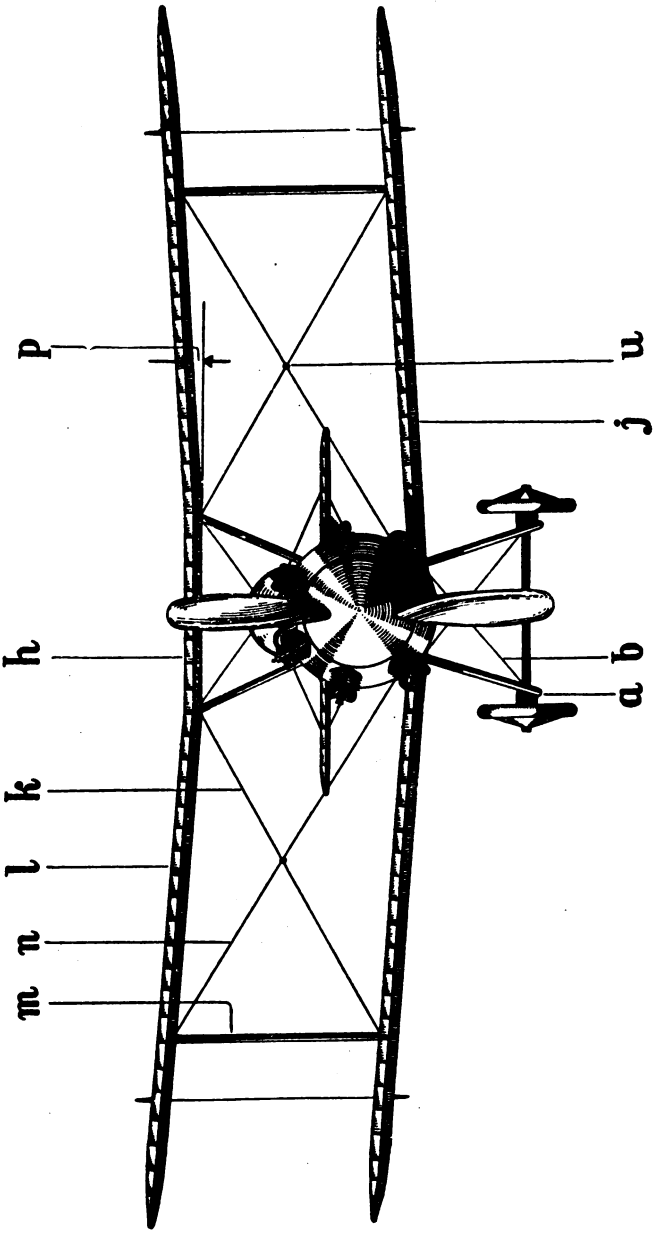


FIG. 87.—Front view of machine.

(8) Place the top plane (*l*) in position by fastening it to the centre plane.

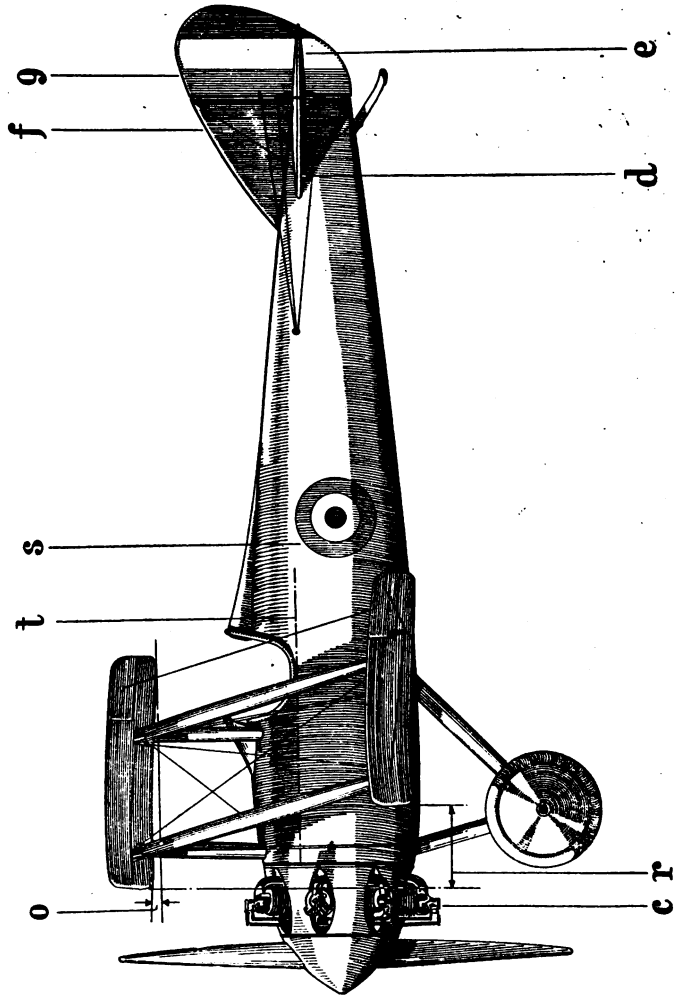


Fig. 88.—Side view of machine.

(9) Insert the struts (*m*) and the flying wires (*n*), and brace up roughly.

(10) True the planes up by the various wires.

The principal terms previously referred to, which affect the rigger, inasmuch as the flying properties of the machine depend largely upon them, are :—

(1) The incidence of the planes shown at (*o*).

(2) The dihedral shown at (*p*).

(3) The stagger, if any, shown at (*r*).

Incidence is the angle at which the leading edge of a plane is inclined above its trailing edge when in position, assuming the centre line of the body of the machine to be dead level. This angle materially affects the speed and the lifting power of a machine. $2\frac{1}{2}°$ to 5° are the most commonly used angles in practice.

Dihedral is the angle of inclination of a plane which causes the outer tip to be above the point at which it is secured. This angle varies according to the requirements of the machine, but 5° is common practice. There are cases in which the top planes are set flat and the bottom planes are set at a proportionately larger dihedral angle.

Stagger is the amount by which, when the planes are set at the correct incidence, the leading edge of the top plane is in front of that of the bottom plane.

When this is reversed—that is, when the bottom plane is in front of the top plane,—it is usually referred to as "negative" stagger.

Incidence, dihedral, and stagger may be said to establish the relationship between speed and climb,

and the three are the development of the designer's attempt to secure inherent stability, which, in other words, is the quality of being uncapsizable in the air. Thus, should a gust of wind throw the machine on an uneven keel, the left wing becomes horizontal or nearly so, and consequently, as the machine falls toward that side, it gives more support or lift, whereas the right wing, having its angle to the horizontal increased, gives less, which obviously tends to make the machine return to an even keel. Longitudinal stability is similarly obtained by setting the tail plane at a lesser angle of incidence to the main planes, so that, should the aeroplane be struck by a gust under the tail plane, thereby tending to force the nose of the machine down, the angle of the same is decreased, and, in fact, becomes negative, *i.e.* the leading edge is lower than the trailing edge, so that direct pressure is exerted on the upper surface, thus forcing the tail back to its original position.

The amount of stagger also has an effect upon the longitudinal stability. Each plane is capable of exerting a certain upward force or "lift," and the position of the combined effect of the lifts of the upper and lower planes, relative to the centre of gravity of the machine, about which it always turns when disturbed during its flight, is materially altered if the stagger is not exactly the amount the designer called for.

Proceeding now with the erection of the com-

ponents, the first of which is the fixing of the undercarriage. Having placed the body or fuselage (*s*) on suitable supports, place the assembled chassis in position, then fix with its pins. This should prove a simple matter as, in the event of suitable jigs having been made, the chassis will have been already assembled on it at points which correspond to the fixings on the body. Then place the bracing wires in position, and tighten up. This is done with the aid of a small spanner, the wires being first of all tightened with the fingers.

The essential point to be watched is that the axle shall be at right angles to both the vertical and the horizontal centre line of the machine viewed from the front and above respectively. First adjust the front diagonal cross-bracing wires until they are equal in length, and at the same time notice that the structure is not being twisted so that the rear strut of the undercarriage is not exactly behind the front strut. Then check the position of the whole undercarriage relative to the fuselage. It is usually best to measure its position from the two lines with plumb bobs, one from each longeron.

Generally the next operation is the placing in position of the engine. In the case of an engine having a platform cast on with holes already drilled, first of all obtain the correct position by means of a template which locates on the bearers, from which the holes are drilled.

The greatest possible care is necessary during this

operation in order to ensure that the engine is placed exactly as called for in the drawings. The engine is one of the principal weights in the aeroplane, and only a slight horizontal displacement from its intended position will be sufficient to appreciably alter the flying trim of the machine.

The bolts are then placed in position and secured with nuts and washers as shown in fig. 89. Care should be taken to ensure a hard surface for the head of the bolt by the addition of washer plate about $\frac{1}{8}$ in. thick, through which the bolt passes.

Two types of washers are shown in the diagram. The ordinary circular type (*a*) is quite well known in engineering practice. The square washer (*b*) is somewhat handier, as it can be made up from odd pieces of rectangular bar, and it also distributes the pressure over a larger surface. These washers should always be made of steel, the various aluminium alloys which suggest themselves from the point of view of weight-saving being too soft and liable to crush when the nut is tightened.

Having checked the position of the engine in relation to the centre line of the body, the next step is the erection of the top centre plane. In the case of the type of machine already mentioned this is usually from 4 to 6 ft. in length, having suitable fittings for the attachment of the struts which support it at the body on one of its centre ribs. The best method to adopt depends on the actual design, but generally it is essential that the

struts be secured to it first; then it is lifted into

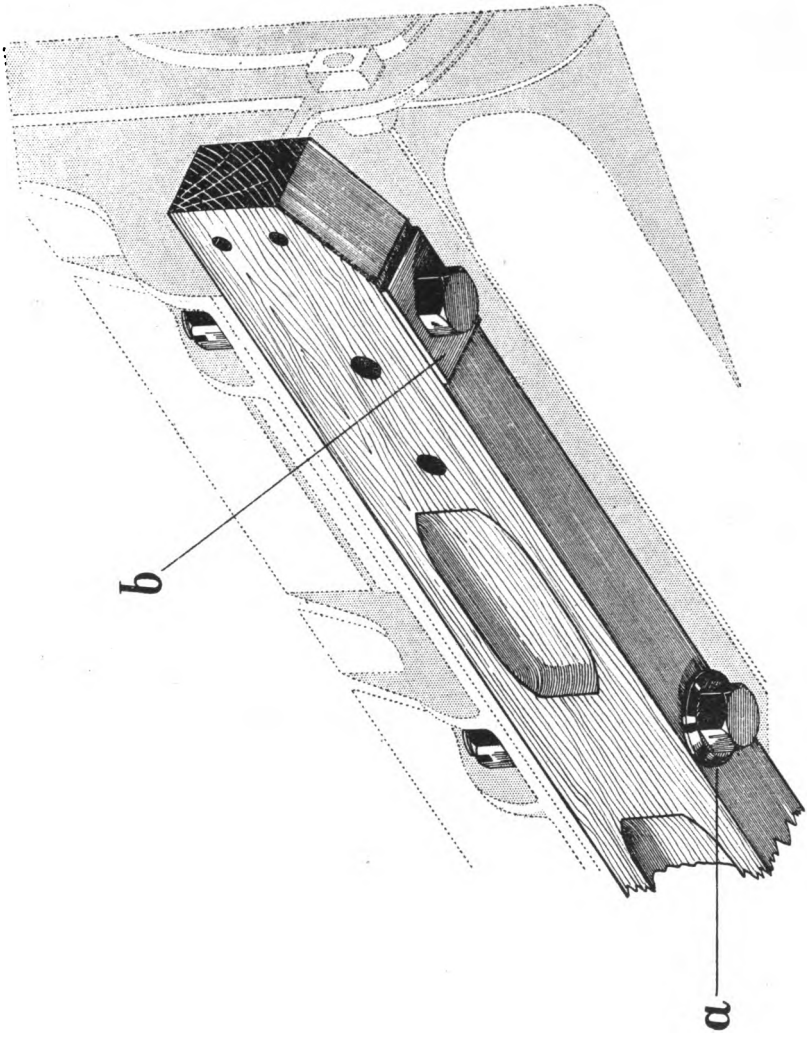


FIG. 89.—Engine mounting.

position over the body, and the necessary fixing carried out. Bracing wires should then be placed

in position and tightened to the required pressure until the correct line is obtained, both as to the relation between the lateral and longitudinal centre line and the angle of incidence. The checking of this angle can be carried out in several different ways. Two of these are illustrated in figs. 90 and 91. The actual method depends on the construction of the body, but it is usual to have the top longeron of the body (see (*t*) in fig. 88) parallel with the centre line of the machine. Should this be the case, the matter is simple. First of all, to check the position of the body on its trestles, an ordinary spirit-level should register zero at any point on this longeron.

It is advisable to use trestles with adjustable tops for this purpose, as a much more accurate and rapid levelling up can be accomplished with these than with ordinary trestles and packing blocks. Figs. 90 and 91 show two methods of measuring the angle of incidence of the main planes of a machine, which will apply equally well to the centre plane now under consideration.

Fig. 90 shows a straight-edge (*a*) laid along the under surface of the plane, upon which an "Abney" level is laid. This level is fitted with a spirit-level (*b*) which carries an arm sliding over a graduated semicircle. The spirit-level is adjusted so that the required angle of incidence reads between the centre line of the arm and the 0° reading on the semicircle. The level is then placed on the straight-

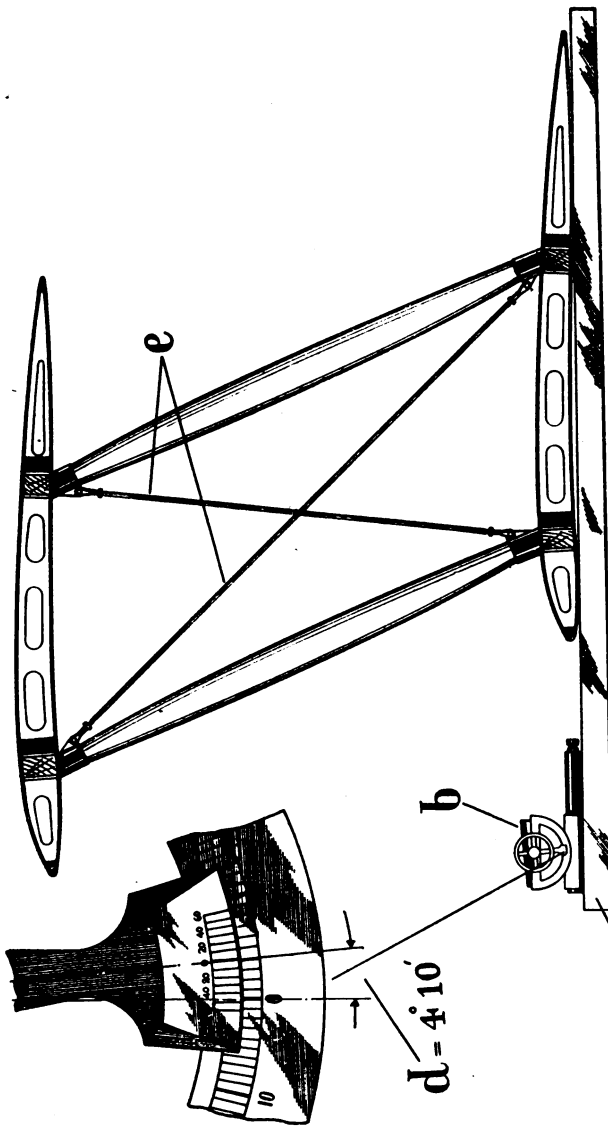


FIG. 90.—Measuring incidence by straight-edge and Abney level.

edge and the angle of the planes adjusted by altering the lengths of the incidence wiring (*e*) until the bubble in the level is central. The same process is followed when using a "field inclinometer" instead of an Abney level. This instrument consists of a large metal quadrant, having the circular edge graduated. An arm, pivoted at the corner of the quadrant, carries a spirit-level on it which has to be brought into a horizontal plane by exactly the same process as just described.

Another method of measuring incidence, which does not call for a special instrument, is given in fig. 91. The straight-edge (*a*) is, in this case, held horizontal—that is, with the bubble in the ordinary spirit-level (*b*) central. If the distance between the centre lines of the spars is known, the height (*d*) for any given angle of incidence can easily be calculated, or the triangle formed can be set out full size on any convenient flat surface and (*d*) measured. The incidence wires (*e*) are then adjusted until the correct height is shown on a steel rule (*c*).

Care should be taken to ensure that no undue strain is exerted on the supporting struts in an attempt to obtain the desired result, as struts are often permanently damaged thereby. This adjustment of the wires is largely a matter of practice. A safe method, however, is to first of all secure finger tightness after and during checking, then tighten each wire separately with an equal number of turns.

The next step is the placing in position of the bottom plane. First of all, support at each end,

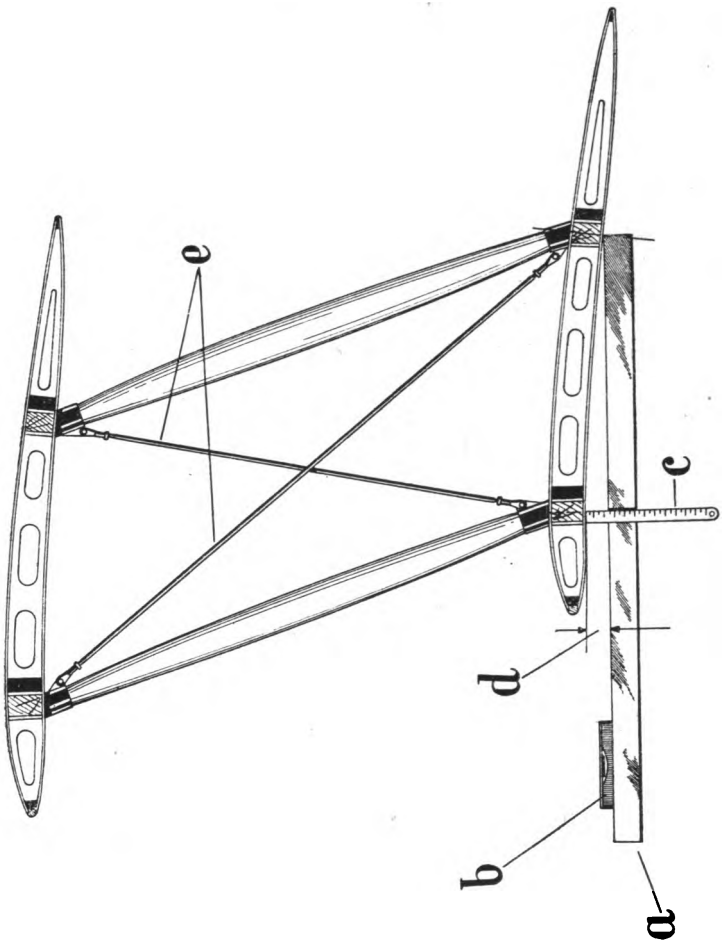


Fig. 91.—Measuring incidence by straight-edge, rule, and spirit-level.

then place the bolts and wires in position and brace up sufficiently to take the weight. The remainder of the components are then placed in position in a

similar manner to that already described for the top centre plane.

The first step in the final truing-up of the machine consists of tightening up with the fingers the landing wires taken in order from the centre of the machine. The tension on the wires should be increased evenly—*i.e.* first of all, tighten the right-hand side, then tighten the left-hand side; having done which give each side, say, three turns with the spanner, and so on. The machine now has all its members erected with wires in position and under tension. The next step is the final truing-up. Commencing from the centre plane, carefully check the incidence angle of each plane as already described, adjusting the tension on the wires until the correct result is obtained. It is here necessary to mention that should the machine which is being rigged require "stagger," the amount of this should be obtained coincident with the checking of the angle of incidence. This should be done by simply hanging a "plumb-bob" (*a*) (see fig. 92) from the leading edge of the top plane and measuring the distance (*d*) between it and the leading edge of the bottom plane, when the plumb-bob is at rest. A level (*b*) should always be held on the rule (*c*) during this operation in order to ensure that the minimum reading at (*d*) is obtained.

This should be checked first of all at the inner and then at the outer edge of the plane.

In checking the dihedral angle, it is sometimes

inconvenient to apply the straight-edge and clino-

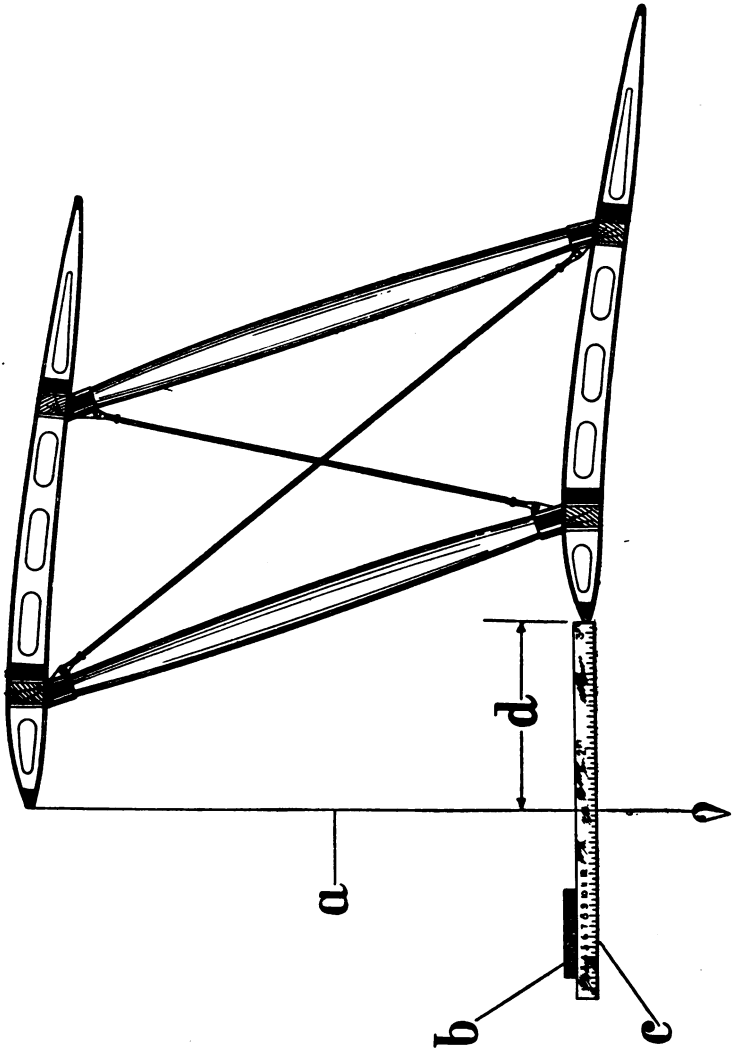


Fig. 92.—Plumb-line method of checking stagger.

meter, in which case the best method is to obtain the perpendicular height by ordinary trigonometrical

rules, and, stretching a thin cord from each outer extremity of the planes, measure the distance between the same and the surface of the top spar at the centre of the machine.

Having checked all the points with a known centre line on the body of the machine, also the distances between the various pin centres of the bracing wires (an error of + or $-\frac{3}{16}$ in. is often allowed), the next step is the checking of the actual security of the various wire and strut joints. Great care is necessary to ensure all pins are properly split pinned. For this purpose the checker is sometimes supplied with a card setting out the various joints and detailing the necessary pins, etc., which are checked individually and marked off on the card accordingly.

The final adjustments of the various wires should be done with the torpedoes (*u*) on fig. 87, or locking pieces in position at the point of intersection of the wires between the various planes, and, having secured them, the wires should be locked in position either by means of wire or lock nuts made of a softer metal than the fitting at the end of the wire.

The torpedoes or locking plates are necessary to prevent the two wires which will be vibrating from chattering one against the other while the machine is in flight. Should these be omitted, this damage will ultimately result in the failure of the wire at this point. It is also usual to bind black adhesive

tape around the wires in cases where torpedoes cannot conveniently be used.

Fig. 93 shows a simple form of torpedo, which is made in either hard wood or else aluminium or one of its many alloys. When made of aluminium it is usually provided with a hard wood strip (*a*) to form a bed for the wires, which otherwise would gradually saw their way through the soft metal. A simple device for the same purpose, known as the "Westland" clip, is shown in the second diagram. This is folded round the wires, and thus forms a good positive and reliable grip, but has not quite the cushioning effect on the vibrating wires that a torpedo has. The lower figure shows two wires bound with ordinary electrical wiremen's adhesive tape, an artifice which is often adopted in the case of an emergency. This method of preventing wires from chattering is invariably used when two wires cross one another in the same plane, as in the case of the incidence wiring on the planes, or the cross bracing in an ordinary girder section fuselage.

The foregoing generally covers the work entailed in the rigging of an aeroplane, but there are of course several incidental operations which call for special mention: amongst these perhaps the most important is the split pinning of the various bolts and nuts and pins in order to lock them in position. Having tightened the nut down to the required position, should an electric brace not be available, take an ordinary drilling brace with a drill the size

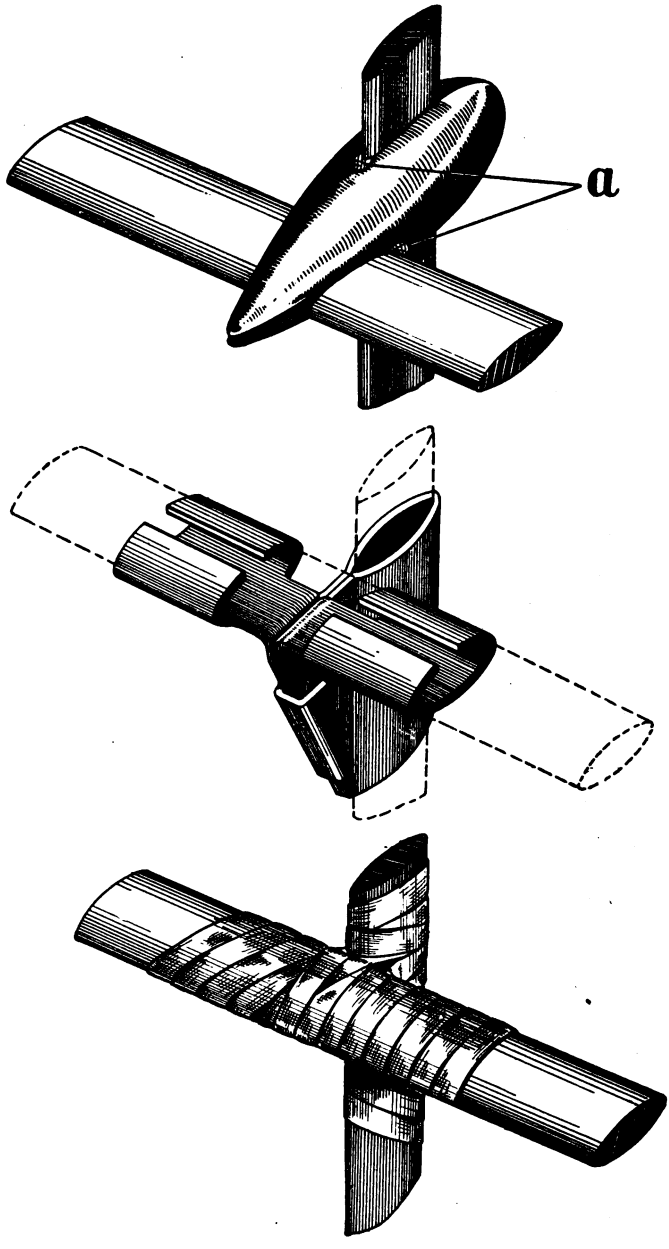


FIG. 93.—Methods of preventing vibration of main plane wires.
Top figure, torpedo; middle figure, locking plate; bottom figure, adhesive tape.

of the split pin required, fixed in a shank, and drill a hole completely through the body of the bolt. Then place the split pin in position, and, after turning the ends outwards with a pair of pliers or other suitable tool, hammer into place around the nut.

The fitting up of the control cables is usually the final step in the erection of an aeroplane. These consist of stranded steel wire rope formed into a loop by splicing at each end. The ends have an inner ferrule of brass or other metal, and a turn-buckle or strainer is inserted at one end in order to secure the required tension. These may be secured or anchored either with bolts and nuts, and split pins, or with the ordinary plain pin merely split pinned. In any case the importance of an anchorage which will not shake loose cannot be over-estimated.

Fig. 94 gives two methods of making splices for loops at the ends of cables which were practically standard practice during the latter part of the late war.

The top diagram is the one used for stranded wire rope, known as "straining cord." The cable is bent round a brass thimble, and then passed through a ferrule (*a*). Three bands of copper wire serving (*b*) are then bound on at intervals. The coils of wire and the bare spaces are then soldered up solid, using a soldering iron, not a blow lamp which may overheat and ruin the wire. The blank ends (*c*) are then frayed out, wound round the cable,

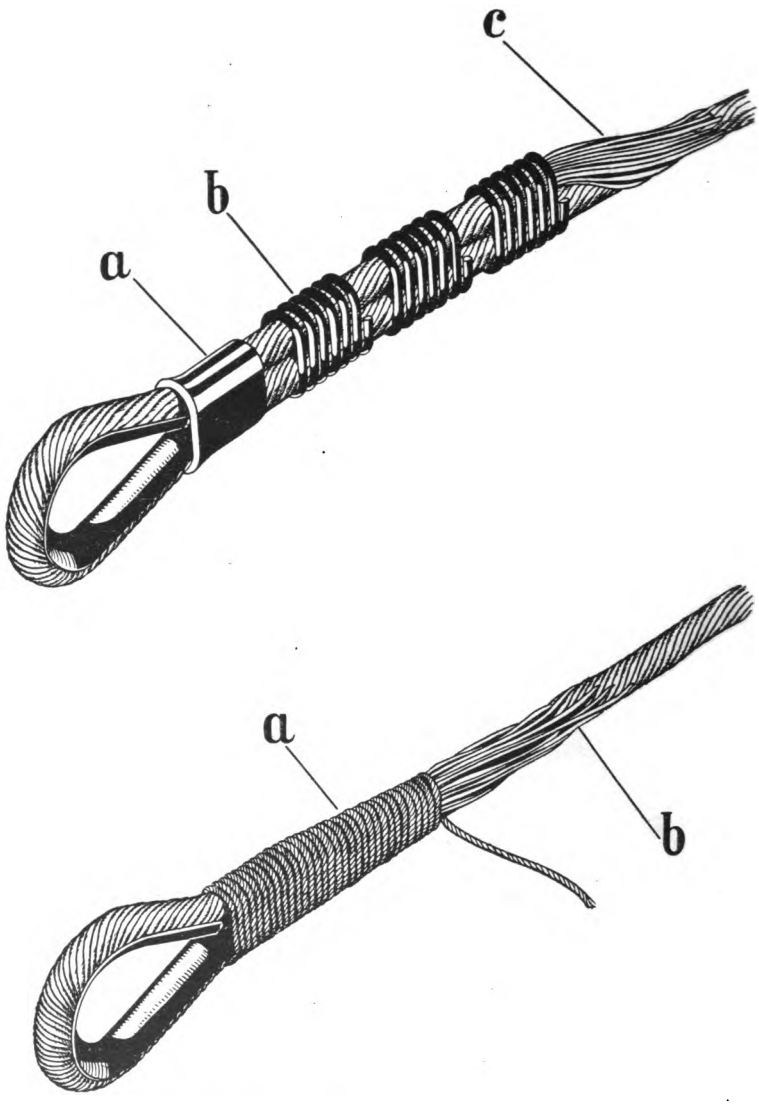


FIG. 94.—Methods of making cable ends.
Top figure, accepted Air Ministry method; bottom figure, ordinary Admiralty method.

and fixed with tarred twine. The lower figure shows an ordinary Admiralty pattern splice for "Extra Flexible" steel cable. The strands of the wire are frayed out at (*b*) and thoroughly interlaced with a sharp pointed tool. The whole is then sweated up solid and finally bound with tarred twine (*a*).

The tools required by a rigger are not elaborate. Equipped with a clinometer, level, straight-edge, hammer, pliers, spanner, drilling brace, and a 60-ft. steel measuring tape, he can carry on.

The trestles used should be of the adjustable type already mentioned, as this obviates the unnecessary waste of time in securing, by the aid of packing blocks, the correct line of the machine required.

Other equipment such as cranes, jacks, etc., is usually supplied according to the size of the machine being rigged.

Notices calling for workmen's attention to the fact that a pilot's life depends upon the accuracy of their work are also not out of place in this department.

INDEX.

Accuracy, limits of, in aeronautical work, 199.
Adaptors for punches, 48.
Adhesive tape for protecting bracing wires, 299.
Adjustable angle plate, use of, in testing, 198.
Aeroplane timber, general description, 83.
Ailerons, jig for building, 144.
Air-pressure testing of castings, 202.
Airscrews, definition of, 150.
— process of manufacture, 151.
Alburnum in timber, 84.
Allowance for spring in bent timber 125.
Aluminium dope, use of, 187.
Angular clearances in dies, 44.
Annealing of fittings after welding, 13.
Apparatus for welding, 12.
Ash, English, defects in, 88.
— — use of, 87.
— Hungarian, use of, 89.
— stacking of, 94.
Assembling jigs for ribs, 122.
Assembly of steel fuselage, 15.

Baffles for tanks, manufacture of, 66.
Balancing and running test for propellers, 169.
— laminations of propellers, 158.
— of finished propeller, 165.
Bark on timber, 84.
Beading dies, description of operation, 40.
— tank shells, 63.
Bending apparatus for steel tubes, 5.
— dies, description of operation, 39.
— steel tube, 3.
— timber, 122.
— — jigs for, 126.
Bevel protractors, description of, 194.
Bits for soldering, description of, 79.
— — use of, 71.
Blackheart in timber, 88.
Blades of propeller, finishing off, 164.
Blanking and forming tool combinations, 39.
— and piercing tool combinations, 35.
— tool, description of operation, 34.
Blocks for box spars, manufacture of, 112.
Blowpipe for welding, 10.
Blue stain in timber, 92.
Body construction in steel, 2.
Bolt and nuts for aircraft work, 25.
— holes in propeller bosses, 164.
Bolster for dies, 54.
Boring propeller bosses, 162, 164.
Box jig, use of, in testing, 198.
— spars, manufacture of, 112.
Bracing wires, final truing up, 228.
— — locking of, 228.
Brazing, liquid, of steel fittings, 18.
— steel fittings, 17.
Breaking down steel sheet for tanks, 61.
Brinell test for metals, 209.
Bulging tank ends, 66.
Butt-ended joints in steel tubes, 7.

Cable, splicing of, 231.
Callipers, indicating, description of, 196.
Castings, examination of, 202.
Cedar, Port Orford, uses in aeroplane construction, 92.
Centre plane, erection of, 222.
Chrome-vanadium steel, uses of, 2.
Clearance constant for dies, 46.
— holes, limits in, 200.
Coarse grain in timber, 91.
Conditioning of timber, 95.

Control wires, fitting of, 231.
Conversion of timber, machines required, 95.
Copying lathe for strut turning, 129.
Cost of use of press tools, comparison of, 29.
Covering planes, processes of, 173.
— propeller blades with fabric, 169.
Cross grain in timber, 89.
Curly grain in timber, 91.
Cutting laminations for propellers, 157.
— timber, 97.
— — economy in, 99.
— — for glueing, 101.

Dancing bolts for strippers, 49.
Deal, White Sea white, uses in aeronautical work, 92.
Defects in English ash, 88.
— in spruce, 90.
Design of metal fittings, practical considerations, 23.
Detachable cover on planes, 181.
Dies, angular clearances required, 44.
— bolster for, 54.
— clearance constant for, 46.
— filing clearances, 45.
— hardening of, 46
— making a typical one, 42.
— repair of, 51.
— sectional, advantage of, 51.
— tempering of, 47.
Dihedral angle, description of, 217.
Dope, aluminium, use of, 187.
— description and specification of, 184.
— -resisting paint, use of, 173.
Doping, effect of, 182.
— fabric, necessity for, 173.
— process of, 181.
Dote in timber, 92.
Drainage holes in planes, 178.
Drilling bolt holes in propeller bosses, 164.
— jig for fuselages, 136.
— — for spars, 106.
— spars, 110.
— versus piercing holes in fittings, 35.
Dunnage for storing timber, 86, 93.
Duramen in timber, 84.

Economy in timber, designing and cutting for, 99.
Ends of tanks, manufacture of, 65.
Engine, fixing, in machine, 219.
English ash, defects in, 88.
— — uses of, 87.
Equipment required for manufacture of steel fuselages, 26.
Erection of steel fuselage, 15.
Extractor for forming dies, 37.

Fabric covering, making up of, 175.
— — of planes, 171.
— — of propeller blades, 169.
Felling timber, 85.
Filing a die, 45.
— and milling marks on punches, 50.
Fillers and caps on tanks, 68.
Filling propeller blades, 166.
Finished propellers, balancing of, 165.
Finishing off propeller blades, 164.
Fish-tail joint in steel tube, 7.
Fitting holes, limits in, 199.
Flux for soldering, application of, 77.
— — making up of, 76.
Forming and blanking tool combination, 39.
— tool, description of operation, 35.
Form templates for propeller, 154.
Foxiness in timber, 89.
Fractures in timber, 90.
Frayed fabric binding on planes, 179.
Fretsaw for cutting rib webs, 121.
Fuselage construction in steel, 2.
— — — assembly of, 15.
— — — piano-wire bracing, 15.
— — — use of tie-rods, 13.
— sockets, manufacture of, 9.
— wooden, erection of, 130.
— — jig for bolt holes, 136.
— — — for building, 134.
— — — for sides, 132.
— — manufacture of details, 114.

Gauze in tank sumps, 70.
Girder type fuselage, erection of, 130.
Glue for propellers, specification, 160.
Glueing, cutting timber for, 101.
— up propeller blocks, 159.

Hard woods for aeroplane construction, 87.
Hardening a die, description of operation, 46.
Heartwood in timber, 84.
Hickory, shagbark, uses in aeroplane construction, 89.

Hinges on planes, fixing of, 144.
Holes for drainage in planes, 178.
Hollow spars, manufacture of, 110.
Hungarian ash, uses in aeroplane construction, 89.

Identification markings of raw materials, 189.
Incidence, angle of, description of, 217.
— — checking of, 222.
Indicating callipers, description of, 196.
Inspection of parts, necessity for, 188.
Interplane struts, assembly of, 147.
— — jig for cutting, 129.
— — manufacture of, 127.
— — use of copying lathe, 129.
— — — of section templates, 128.

Jig for aileron erecting, 141.
— assembling ribs, 122.
— bending timber, 126.
— cutting interplane struts, 129.
— drilling holes in fuselages, 136.
— — spars, 106.
— erection of complete fuselages, 134.
— fuselage sides, 132.
— hollow or box spars, 111, 113.
— interplane strut assembly, 147.
— longeron assembling, 131.
— monocoque fuselages, 138.
— profiling ribs, 116.
— propeller glueing up, 160.
— recessing ribs, 119.
— trailing edge fixing, 141.
— wing erection, 139.
Joints in steel tubes, 6.
— in tank shells, 61.

Kiln drying of timber, 95.
Knots in timber, 88, 91.

Lamination for propeller, balancing of, 158.
— — cutting of, 157.
— — glueing up, 159.
— — toothing of, 157.
— templates for propellers, 152.
Lead plugging of propellers, disadvantages of, 165.
Length of punches, 51.
Lightening holes in ribs, cutting of, 120.
Limits of accuracy in aeronautical work, 199.
Liquid brazing steel fittings, 18.
Log band saws, functions of, 95.
Longerons, assembling of, 131.
Lower plane, fixing of, 225.
Lugs and sockets, limits on, 200.

Main plane spar, manufacture of, 105.
Materials for covering planes, 171.
— suitable for tank-making, 82.
Medulla in timber, 84.
Medullary rays in timber, 84.
Metal fittings, examination of, 204.
— — normalising of, 204.
— — practical consideration in design of, 23.
— sheathing and tipping of propeller blades, 166.
Micrometer, description and use of, 190.
Mild steel, uses of, 2.
Milling and filing marks on punches, 50.
Moisture contents of timber, 95.
Monocoque fuselage, jig for erection, 138.
Mykarms, use of, on micrometer, 190.

Neutral flame in welding, 10.
Nibbling machine, use of, 24.
Nickel-chrome steel, uses of, 2.
Nuts and bolts for aircraft work, 25.

Oil tanks, general description, 55.
Over-maturity in timber, 88.
Oxy-acetylene welding process, 10.

Pegging of propellers, 162.
Petrol tank ends and baffles, manufacture of, 65.
— tanks, assembly of details, 71.
— — general description, 55.
— — testing of, 75.
Piano-wire bracing in steel fuselage, 15.
Piercing and blanking tool combinations, 35.
— versus drilling holes in fittings, 35.
Pins and shafts, limits on, 200.
Pith in timber, 84.
Plane erection, jig for, 139.
Planes, truing up of, 139, 142.
Planing machine, hand feed, 102.

Planishing hammers, use of, 66.
Plug gauges, description of, 194.
Port Orford cedar, uses in aeronautical construction, 92.
Precautions during assembling fuselages, 115.
— — brazing fittings, 18.
— — covering planes, 175.
— — liquid brazing of fittings, 20.
— — soldering tanks, 71.
— — sweating up sockets, 16.
— in setting a punch and die, 49.
— to be observed in die-making, 44.
— — — in welding, 12.
Press tools, blanking and forming tool combinations, 39.
— — choice of machine for particular job, 30.
— — classification of, 27.
— — comparison of costs in use of, 29.
— — necessity for templates, 30.
— — operating a beading die, 40.
— — — a bending die, 39.
— — — a blanking tool, 34.
— — — a forming tool, 35.
— — suitable articles for manufacture, 28.
— — typical machine, description of, 32.
Profiling jig for ribs, 116.
Propellers, definitions of, 150.
— process of manufacture, 151.
Protection for sewn edges on fabric cover, 175.
Protractors for angular measurements, 193.
Punches, description of manufacture of, 48.
— lengths of, 51.
— repair of, 51.

Quantity lists, use of, 104.
Quebec spruce, use in aeronautical construction, 92.

Radius on forming dies, 37.
Rammy grain in timber, 88.
Reciprocating frame saws, functions of, 95.
Red spruce, use in aeronautical construction, 92.
Repairing dies and punches, 51.
Resin pockets in timber, 91.
Ribs, examination of, 209.
— for wings, manufacture of, 115.
— — jigs for, 118, 119.
Ribs, lightening holes, cutting of, 120.
Rift sawing of timber, 97.
Rigging an aeroplane, general limits, 213.
— — sequence of operation, 214.
Rivet holes in tank shells, 58.
Roche vernier calliper, description of, 192.
Roller feed circular saw, 102.
Rough shaping of propeller, 163.
Running and balancing test of propellers, 169.

Sand-blasting fittings, 21.
Sapwood in timber, 84, 89.
Screw gauges, description of, 195.
Screwing sheaths to propeller blades, 168.
Scribing block, use of, 199.
Seams in fabric covers for planes, 175.
Section templates for struts, use of, 128.
Sectional dies, advantage of, 51.
Selection of planks for propellers, 156.
Setter-out's duties, 104.
Sewing on fabric covers for planes, 176.
Shadow projection for examining threads, 195.
Shafts and pins, limits on, 200.
Shagbark hickory, uses in aeroplane construction, 89.
Shakes in timber, 89, 92.
Sheathing and tipping propeller blades, 166.
Sheet metal fittings, examination of, 204.
— — — normalising of, 204.
— — limits on, 201.
Shell of a tank, general requirements, 57.
— — making beading, 63.
— — manufacture of, 58.
— — types of joints, 61.
Shrinkage of timber, 98.
Skids for storing timber, 86, 93.
Sockets and lugs, limits on, 200.
— design of, 16.
— manufacture of, 9.
Soft woods for aeronautical construction, 87.
Solder, manufacture of sticks, 81.
Soldering bit, uses of, 72.
— — description of, 79.
— flux, application of, 77.
— — making of, 76.

Soldering, general instruction, 78.
— propeller sheaths and tips, 168.
— stoves, description of, 80.
Spar rod, use of, 105.
Spars, main plane, manufacture of, 105.
Spindling out recesses, 107.
Spiral grain in timber, 91.
Splicing cables, 231.
Split pinning nuts during final erection, 231.
Spray painters for dope, 183.
Spruce, Quebec, uses in aeronautical construction, 92.
— red, uses in aeronautical construction, 92.
— Sitka, defects in, 90.
— — uses in aeronautical construction, 90.
— stacking of, 94.
— West Virginian, uses in aeronautical construction, 92.
Stacking planks, 93.
Stagger of planes, checking of, 217.
— — description of, 226.
Steam chest for timber bending, 124.
Steel, chrome-vanadium, uses of, 2.
— construction, advantage of, 2.
— — particular application, 1.
— fittings, brazing of, 17.
— — equipment required for manufacture, 26.
— — liquid brazing of, 18.
— — tinning of, 8.
— mild, uses of, 2.
— nickel-chrome, uses of, 2.
— tubes, bending of, 3.
— — in bodies, 2.
— — jointing of, 6.
Sticks for stacking planks, 93.
Storing and transporting propellers, 170.
— timber, 86.
Strength of aeroplane fabric, 172.
Strippers for punches, 49.
Struts, examination of, 209.
— interplane, assembly of, 147.
— — manufacture of, 127.
Sump for tanks, manufacture of, 69.
Surface plate, use of, in testing, 198.
Surfacer and thicknesser, use of, 103.

Tank, assembling of details, 71.
— ends and baffles, bulging of, 66.
— — — manufacture of, 65.
— filler and cap, fixing of, 68.
— final test of, 75.
Tank, petrol, oil, and water, general description of, 55.
— shell, general requirements, 57.
— — making the beading, 63.
— — manufacture of, 58.
— — types of joints, 61.
— sumps, manufacture of, 69.
— tie-rods, fixing of, 67.
Taping ribs, necessity for, 173.
Tempering a die, description of operation, 47.
Template for die-making, use of, 42.
— for pressing, use of, 30.
— for propeller laminations, 152.
— — form, 154.
— for recessing ribs, 119.
Testing of aeroplane fabric, 172.
Tests of raw material, 189.
Thicknesser and surfacer, use of, 103.
Through-and-through sawing of timber, 97.
Tie-rods in steel fuselages, 13.
Tilghman's sand-blasting apparatus, 21.
Timber, bending of, 122.
— conditioning of, 95.
— cutting of, 97.
— felling of, 85.
— for aeroplanes, general description, 83.
— measuring moisture contents, 95.
— shrinkage of, 98.
— storing of, 86.
— use of dunnage, 86.
— — of skids, 86.
Tinning of steel fittings, 8.
Tipping and sheathing propeller blades, 166.
Toothing propeller laminations, 157.
Torpedoes for locking bracing wires, 229.
Trailing edge, fixing jig for, 141.
Transporting and storing propellers, 170.
Truing-up machine, use of, 103.
— up of planes, 142.
— up planks, 103.
Tube-bending apparatus, 5.
Tubes, examination of, 209.
— limits on, 200.
Tubular parts, design of, 5.
Twisted fibre in timber, 91.

Undercarriage, fixing to machine and truing up, 219.

Varnishing planes, 185.
— propeller blades, 166.
Vernier calliper, description and use of, 190.

Wadkin propeller shaper, use of, 163.
Warp in fabric covering, 171.
Washers, use of in engine mounting, 220.
Water tanks, general description, 55.
Weft in fabric covering, 171.
Weight required for making pressings, 30.
Welding, annealing of fittings, 13.
Welding apparatus, 12.
— blowpipe, 11.
— for tubes and plates, 10.
Westland clips for locking bracing wires, 229.
West Virginian spruce, use in aeroplane construction, 92.
White Sea white deal, use in aeroplane construction, 92.
Wing erection, jig for, 139.
— ribs, manufacture of, 115.
— truing of, 142.
Wood filler for propeller, 166.
Woodwork, general examination of, 209.

(PR. 36)

PRINTED IN GREAT BRITAIN BY NEILL AND CO., LTD., EDINBURGH.